SELECTIVE SIGNALLING USING AN INDUCTIVE LOOP

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BY
MAJOR K. DWARAKANATH

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CERTIFICATE

Certified that the work entitled "SELECTIVE SIGNALLING USING AN INDUCTIVE LOOP" has been carried out under my supervision and it has not been submitted elsewhere for a degree.

S.K. Mullick
Assistant Professor
Electrical Engineering Department
Indian Institute of Technology, Kanpur

August 1, 1972

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- Major K. Dwarkanath

Kanpur
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ABSTRACT

There are a number of instances wherein a selective signalling system has to work only in a confined area of space or locality like for example a multi-storeyed building, a hospital, or a small factory, or a construction site. Selective signalling finds application in paging and remote control fields. An attempt has been made here-in to develop a methodology for the design of a system which uses an inductive loop around the area. The intelligence is moved by means of a carrier frequency in the LF range. The receivers contained within the area operate on the principle of induction. A prototype transmitter and receiver have also been fabricated and this paper includes the design criteria employed in their construction.

CHAPTER 1

GENERAL SYSTEM CONSIDERATIONS

1.1 AIM

To design and develop a prototype for a selective signalling system which is capable of operation within a confined area of space or locality and which can be used for paging or remote control applications.

1.2 INTRODUCTION

There exists various techniques for remote accessing of any one selected address from out of many by employing communication principles. Such a selective addressing system has applications in the fields like paging, industrial telemetering and remote control etc. In a districtwise paging system for example, any one subscriber out of possibly a few thousands can be selectively contacted from a base control station. In remote control applications selective addressing may be employed for controlling numerous machine functions. The various techniques differ according to the frequency, modulation and decoding methods employed. The choice of frequency is invariably dictated by the available slots in the existing frequency spectrum whereas the modulation and decoding schemes are

factors mostly influenced by desired receiver size, no. of addresses, availability of simple and reliable hardware and cost.

There are numerous instances wherein it would be sufficient if the selective signalling system works only in a confined area of space, e.g. paging systems for hospitals, small factories, commercial warehouses, construction sites, summoning drivers from parking lots etc. Situations where selective signalling could be used for remote control/command purposes are controlling of certain machines on a shop floor, industrial processes, hobby flying, controlling model trains and boats, advertisement and educational displays, remote handling of radio isotopes in a nuclear establishment, remote control of patient monitoring equipment in a hospital etc. As far as military applications are concerned there are numerous possibilities like alerting pilots for take off on intercepting or bombing missions, selective blasting of mines, remote control of target equipments for rifle firing practices, command and control of gun position etc.

The aim of the project being as that stated already, let us review some of the existing systems and look at other possibilities before making a choice.

1.3 A 150 MCs PERSONAL RADIO PAGING SYSTEM (1,17,20,21)

Basically this experimental system extends the telephone bell to the customers pocket. Three transmitters are installed in the lower part of MANHATTAN, New York City, to give coverage to practically all locations below 59th street. The range is about 4-1/2 miles. THis system provides direct customer dialling. It caters for 3200 subscribers. Audio tones are employed for coding. Decoding mechanisms in the receivers are reed relays. Even with 250 watt transmitters and high performance receivers the range into modern steel reinforced buildings is only about one and a half miles and into big city streets it is about five miles.

1.4 CITY WIDE PERSONAL SIGNALLING AT ALLENTOWN-BETHLEHEM (2)

This system enables a subscriber to reach a called party even if he is not in the immediate vicinity of his telephone. There are two AM transmitters having an output of 250 watts each operating in the 35 mc band. Coding is done by 9 different audio tones which range from 160 cps representing digit 1 to 301.18 cps which corresponds to digit 9. The choice of audio frequencies was dictated by the decoding mechanisms in the receiver which were tuned vibrating reeds. The audio tones corresponding to the digits of the desired code to be transmitted are sent as bursts of 0.5 seconds duration each with a gap of 0.15 seconds between bursts. There is a guard band of 3.2 secs. between code groups. The number of subscribers is 3200.

Outdoor range is from 3 to 5 miles with receivers having a sensitivity of 40 to 56 db above 1 microvolt per meter. The range into buildings is 0.5 to 1.0 mile on the first floors.

1.5 POCKET BELL PERSONAL RADIO SIGNALLING SERVICE (3)

This is a new mobile radio service in operation in JAPAN with effect from July 1968. The system uses 150 MHz for carrier frequency and the composite audio tone coding method using a number of voice frequencies. Frequency modulation has been employed. For a radius of coverage of 20 KMs, there are 8 distributed base stations each transmitting 250 watts of power simultaneously. The system can cater for 10,000 subscribers in one channel.

1.6 SELECTIVE PAGING SYSTEM USES CODED TRANSMISSION (4)

This system operates on the principle of induced magnetic field. A loop antenna surrounds the area or the building to be covered and is excited by a transmitter. Upto 45 individual addresses may be selected. Selected receivers attract attention by a buzzer or flashing lamp. The calling signal consists of a selected carrier frequency keyed on and off at a predetermined rate as shown in chart below.

First digit	Carrier fr	Second digit	T(secs)
1	16 KHz	1	1/76
2	20.6 KHz	2	1/84
3	18 KHz	3	1/92
4	24 KHz	4	1/100
5	28.8 KHz	5	1/111
		6	1/124
		7	1/135
		8	1/147
		9	1/162

For example receiver number 24 is tuned to a carrier frequency of 20.6 KHz at a repetition tone of 1/100 of a second. Decoding at the receiver is done by resonant reed relays. The keyed RF carrier is picked up by a ferrite antenna at the receiver and amplified. When the incoming pulse rate is the same frequency as the resonant reed, the relay contacts interrupt current flowing through a miniature loud speaker to cause an audio tone to be generated. The receivers require a field strength of 50×10^{-6} certedts and uses two rechargeable batteries of 150 ma hours.

1.7 BUILD THE LIBERATOR (5)

This idea affords freedom of movement to hams as they are relieved of the necessity to sit tied down to their receivers in anticipation of a call. The audio output of the receiver is directly fed into a loop and

the listener carries a pocket receiver and can freely move around within the loop. The transmitting loop and the receiver loop act as a transformer. With transmitting loop wound around the main floor, excellent reception was obtained from basement to attic of a typical 3 storey brick structure.

The 100 mw output from a conventional pocket receiver was used to power a 30' x 50' loop. A good magnetic field was found 25' above the loop (It might have been higher but the house was'nt!).

1.8 NEEDS TO BE FULFILLED BY A COMMUNICATION LINK(7)

When one starts contemplating the establishment of a communication link the following major factors are to be reckoned with before deciding on the choice of the particular system.

(a) Intelligence to be moved

(b) Reliability of the communication link

(c) Worst case signal condition expected

(d) Geographical considerations

(e) Frequency and Bandwidth available

(f) Power levels to be handled

(g) No of subscribers to be catered for

(h) Future expansion

(i) State of the art in hardware technology

(k) System economics.

1.9 CHOICE OF SYSTEM FOR THE APPLICATION IN HAND AND ITS RATIONALE

As opposed to the first three paging systems discussed above, in the present case of selective signalling the major need is the operation of the system within a confined area of space or locality whose boundaries are clearly known before hand. While the intelligence to be moved (i.e. some form of code which decides the address to be accessed) remains more or less the same as in the above cases, the area of coverage and the number of addresses to be catered for per channel would be a known quantity and substantially less. The small size of the service area offers further advantages in the sense that the power levels to be handled are considerably less and the worst case signal condition to be expected is a quantity that can be evaluated precisely. With a priori knowledge of these quantities, the extent of hardware dependability would be a factor which decides the system reliability to a great deal.

The frequency and bandwidth to be employed in communication links are bound by certain international rules and regulations and hence the choice is perforce restricted. The existing RF spectrum is already over congested and as such ITU allocation permits only the use of 50 to 54 MHz, 144 to 146 MHz and 146 to 148 MHz slots in the VHF range for use by amateurs. The

communication link at these frequences is by line of sight (LOS) and hence suffer from relatively large diffraction losses due to obstacles. Because of this the power requirements have to be high. Also power transistors at these high frequencies are difficult to obtain indigenously. Besides the transmitter and receiver construction is inherently complex. Hence for a confined area of space not much benefits are to be obtained by the use of VHF.

Alternatively one can use the LF range where the spectrum is less crowded. The major drawback of LF communications is that both the transmitting and receiving antennae have to be very long as the wave lengths are in the kilometric region. However, this does not prohibit the use of a thin conductor of wire strung around the limited area of space to act as a transmitting loop of wire. Moreover very low loss ferromagnetic core materials are available these days which have very high permeability and are capable of operation from DC to 1000 KHz. Use of such a core material in the receiver would reducethe size of its antenna.

The transmitting loop of wire could carry a current with a frequency of a few tens of kilohertz with the receivers being located within the confines of the area (and to a certain extent outside also) and working on the principle of magnetic induction. In a multistoreyed

building for example the conductor of wire could be concealed in wall or ceiling mouldings. By making the transmitting loops length of the order of $\lambda/10$, current at any two points along the entire length of the conductor can be considered to be inphase. When two parallel conductors carry current which are in phase but which flow in opposite directions, the magnetic field produced is additive in nature in the space between the conductors and tends to progressively cancel out at larger distances external to the conductor. The length of the loop of wire being kept a small fraction of the wavelength, it will be a poor radiator and hence will not adversely affect other systems operating in the same frequency range much outside the loop.

The advantages of a such system would be -

(a) Relatively lower power levels

(b) Easier allocation of the communication link frequency (it appears that licensing may not even be necessary)

(c) Simplicity of transmitter and receiver construction.

(d) Relative freedom in the choice of bandwidth.

(e) Greater reliability owing to less liability to diffraction, fading, atmospherics etc.

(f) Greater economy.

Other characteristic technical considerations are discussed in chapters to follow. With the foregoing

discussions in mind, it was decided to set up an experimental loop employing a frequency in the super audio range with receivers working on the principle of magnetic induction. In the next chapter various preferred techniques that are employed in this system are discussed indicating the rationale behind each choice.

CHAPTER 2

SYSTEM CHARACTERISTICS and SPECIFICATIONS

2.1 Before one formulates the system specifications, it is necessary to make a comparative study of techniques available in order to effect an appropriate choice of the system parameters.

2.2 <u>FREQUENCY</u>

As already stated in Chapter 1, the envisaged receiver works on the principle of induction using the near field of the loop antenna of the transmitter. In order to ensure that there are no nulls in the magnetic field within the loop, it is required that the current be in phase between any two points on the loop. As a thumb rule for this purpose normally a conductor which is not longer than a tenth of the wave length is adopted. Going above 0 to 20 KHz in the audio spectrum to avoid interference in this range one can use frequencies upto 200 KHz. Behond 200 KHz the allocation is reserved for aeronautical aids and from about 525 KHz commercial broadcast spectrum commences. For a loop length of say 400 meters, the frequency to be employed according to the thumb rule works out to be 75 KHz.

2.3 ENCODING AND DECODING(16)

There are numerous ways in which intelligence can be coded and moved by using a carrier freqncy. The summary below indicates various methods available for this purpose.

Sl. No.	Information or Intellegence	Accessing Method	Decoding
1	Audio tones or bursts	Mechanical/Electrical resonance	Resonent reeds, L.C. tuned circuits, RC bridge
2	Variable RF	Electrical resonance	LC tuned circuit
3	Variable pulse delay	Delay reference between code and reference pulses	Electrical/acoustical delay lines
4	Pulses	Discrete combination of positive and negative pulses	Electromagnetic storage devices
5	A series of pulses	Counting techniques	Electronic counters

In what follows we shall briefly see the underlying techniques of each of the above methods of encoding and decoding and the associated advantages and disadvantages.

2.4.1 Resonant Reed System

Usually a number of audio tones are employed for coding and RF is used as a carrier. The choice of audio frequencies chosen is dictated by the electromechanical decoders in the receiver which are tuned vibrating reeds.

The reeds may be sequentially excited or simultane-ously (by using some storage elements). The coding capacity in such a system is given by $C_f = N^m$ where N is the total number of resonators and m units are used in the decoder. In a simultaneous system $C_f = {}^{N}C_m$ holds. The main advantage of this technique is that the state of the art is relatively old. Also some of the electronic hardware is dispensed with as the decoding mechanism is non-electronic. The disadvantages are -

(a) The interface between the mechanical resonator and electrical driving circuitry is quite inefficient.

(b) The mechanical reeds cannot match the order of reliability obtainable by using electronic equivalents.

(c) Physical size of the reeds restricts the number of them that can be used in a miniature receiver.

(d) For resonance to be achieved the duration of the excitation has to be sufficiently long. As such it imposes an upper limit on the call handling capability of the system. For example with a 3 digit system, a maximum of about 12 code groups per minute can only be transmitted catering for a 0.5 sec. duration of each of the three audio tones and an intertone gap of 0.15 sec and a guard band of 3.2 secs between each-code group.

2.4.2 Variable RF

The RF spectrum could be divided into a number of transmitter frequencies with fixed tuned receivers. However considering that only 5 MHz slots are available in the VHF range, the receiver tuned circuits will have to be designed for very narrow bandwidths and the resulting Q's will be non practical to achieve.

2.4.3 Use of Pulses

One can resort to a digital system using a combination of discrete binary values of 0 and 1 for purposes of coding. The inherent advantage of the digital system over the analog system is one of accuracy. In such a system the number of digits required for accessing any one of M receivers must be equal to the smallest integer greater than or equal to the base 2 of M.

The digital system has a disadvantage that it is relatively more complex. However, such considerations donot pose any limitations owing largely due to the present day state of the art. With the advent of digital integrated circuits complex digital circuitry lend themselves for easy assembly merely by the use of ICs as building blocks. Cost and powerwise also they are comparable to analog devices. Use of these ICs make possible miniaturisation.

2.4.4 Variable Delay

Code correspondance is obtained by using the variable delay between a reference pulse and a coding pulse.

The coding delays are of the order of milliseconds. Hence lumped circuit and piezo electric precision delay lines occupy a large space in a receiver.

2.4.5 Series of Pulses

This compares favourably with the binary coded system enumerated at para 2.4.3. In this technique a predetermined number of pulses are sent. At the receiver code correspondance is indicated when the count matches the present number. The number of pulses sent is on an average 20 times that in the binary code system. Hence it is more prone to bit error.

2.4.6 Number of Pulses Equals Digit (NOPED)

This is a slight modification to the above system of a series of pulses. A number of pulses equal to each of the decimal digits of the address with necessary inter digit gap is transmitted. At the receiver a counter keeps a count of the pulses corresponding to each of the digits. Code correspondance is obtained when the incoming code matches that which is preset in the receiver. This method is quite feasible and reliable and is more attractive in many ways to the series of pulses technique described above. However hardware realisationwise it is a little more involved than the binary coded pulse system.

2.4.7 Choice of Encoding Technique

In view of the foregoing discussion the choice was made in favour of the binary coded selective signalling technique. It is the most suitable because of its reliability, relative simplicity of encoding and decoding and its adaptability to future exapansion. System cost and effectiveness wise also it appears to be the best compromise.

2.5 CARRIER KEYING METHOD(6)

There are three basic methods known as -

(a) 'ON-OFF' keying

(b) Frequency shift keying (FSK)

(c) Phase shift keying (PSK)

These three methods are illustrated in Figure 1(a) to 1(c). Let us now briefly analyse the techniques with a view to choosing the one that meets the requirements in the present application.

2.5.1 ON-OFF keying

An audio tone oscillator is used to switch the carrier ON or OFF depending upon the code. The oscillator is usually permitted to run continuously to maintain frequency stability and the amplifier is turned ON and OFF to transmit the mark and space pulses. The amplitude of the signal changes from a maximum amplitude as delivered by the

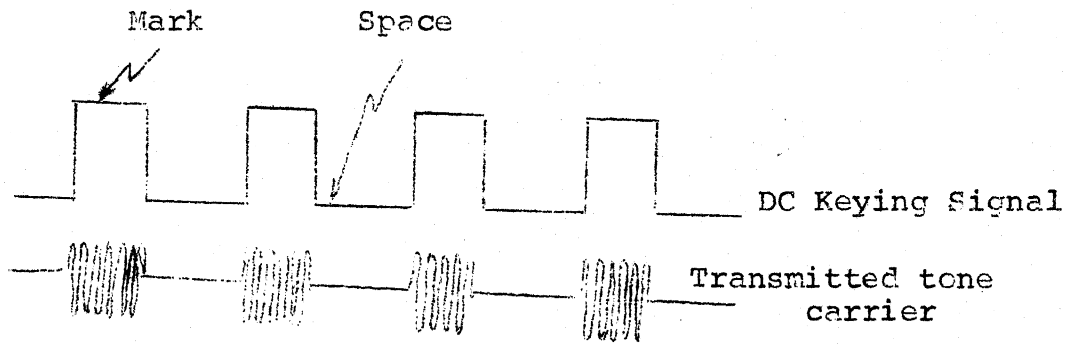


Figure 1(a): AM Tone Carrier or 'On-Off' keying Method

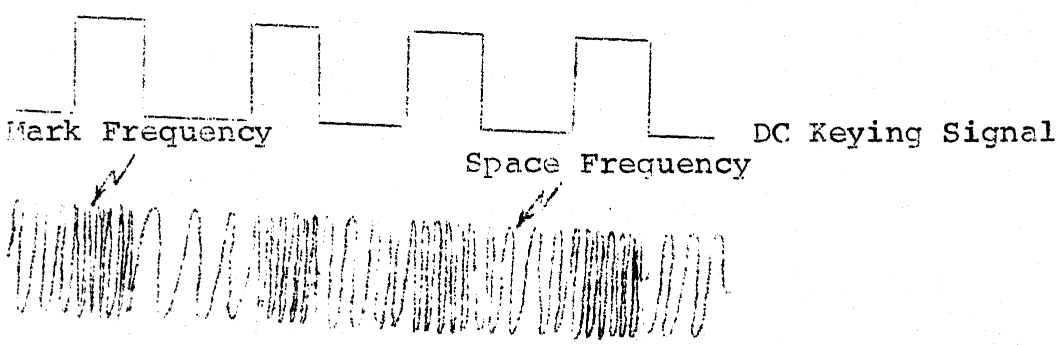


Figure 1(b): Frequency Shift Keying (FSK)

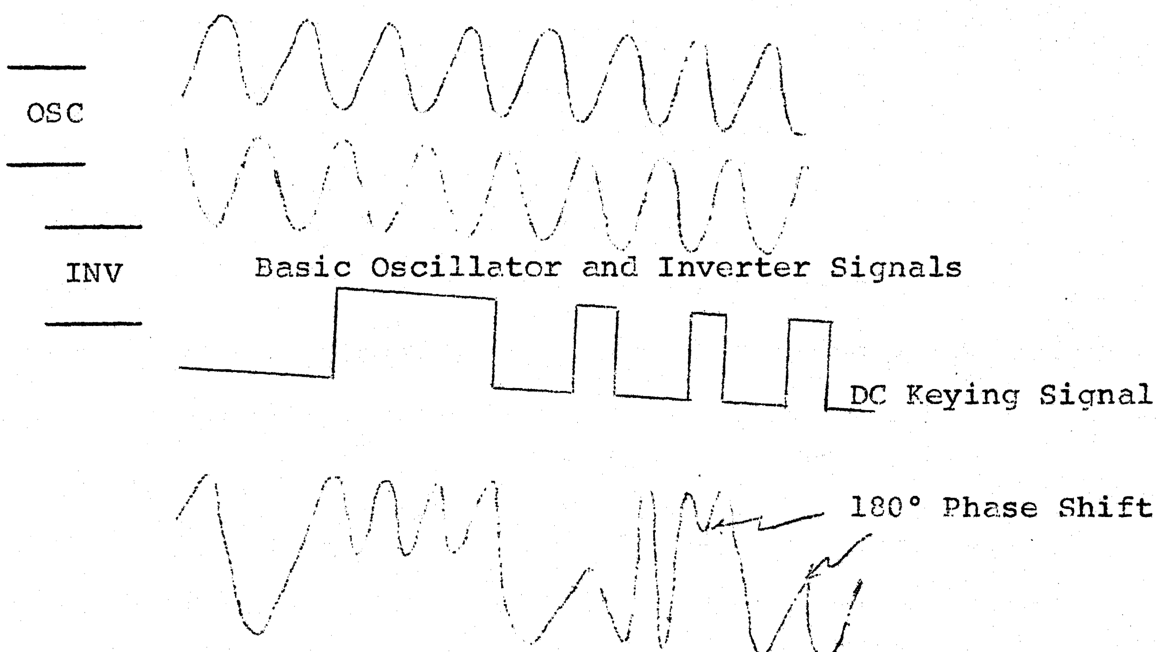


Figure 1(c): Phase Shift Keying

(In PSK space is transmitted as a steady signal from either oscillator, while mark is transmitted as a 180° phase shift)

amplifier to no amplitude when the transmitter is keyed off. The signal is amplitude modulated. It is to be noted that in AM audio tone carrier the steady state no transmission period is usually called a space and the keyed on data are called marks. The message is transmitted as a series of mark pulses.

2.5.2 Frequency Shift Keying (FSK)

The two state mark-space data can be transmitted as two separate frequencies by use of frequency shift techniques. The basic oscillator of the amplitude modulating system is equipped with two frequency determining components and these are switched. In this method the amplifier is not keyed and an AC signal of either one or the other frequency is continuously transmitted. One of the oscillator frequencies is transmitted continuously and corresponds to the steady state space condition. Pulses are transmitted by switching in frequency changing component and transmitting a signal of different frequency but of the same amplitude. As the keying signal does effectively modulates the frequency of the carrier this system is some times called the FM. By convention the carrier frequency of transmission is assumed at the centre between the two actual transmission frequencies even though the centre freqnency is not transmitted.

Similarly the mark and space frequencies which are actually sent are defined as cycles of deviation above or below the centre or carrier frequency. In certain specific applications the centre frequency is transmitted and detected. This is 3 state FSK with states defined as Mark, Neuter and Space.

2.5.3 Phase Shift Keying (PSK)

Unlike FSK and AM where a number of carrier cycles are required to transmit one cycle of data, PSK inserts one cycle of mark-space data into each cycle of carrier allowing the keying frequency to be the same as the carrier frequency. The 180° phase shift is made as the signal current passes through zero as shown graphically in Figure 1(c). The PSK receiver contains a free running oscillator which is kept in synchronism with the incoming signal is compared in a phase detector circuit. If the incoming signal phase is the same as the oscillator signal a space is received. If they are different a mark is received.

2.5.4 Comparative Merits of the Three Keying Methods

The AM tone carrier is the easiest to build and understand. It is entirely practical so long as the path noise is minimal and the signal attenuation in the path is fairly constant. However, when noise is high or the path losses vary widely FSK is preferred.

The FSK has a number of advantages over the AM. The primary advantage is in the area of noise rejection. Noise included or coupled into the signal during transmission is in the form of an a.c. signal of completely random frequency and amplitude. Since the AM receiver is not frequency sensitive it may respond to such an unwanted signal reaching its input. Any signal arriving during a space time could be detected as a false mark. On the other hand, in FSK unwanted signals of random frequency will not be recognized as the receiver keeps looking for only two specific frequencies. The natural selection of FSK is aided by the fact that one of the two frequencies is always present. Any spurious inputs must have sufficient power to override the mark or space signals to cause false outputs. For these reasons FSK will operate in worse signal to noise ratios.

PSK offers considerable gain in the speed of transmission of individual mark-space pulses. However it is more sophisticated, more difficult to maintain and requires a very good communication path. Its use is justified only in large sophisticated digital telemetering systems or for data transfer work.

2.5.5 Choice of Carrier Keying Method

In the present application the communication path extends to only a confined area in which a certain minimum field strength is maintained by suitable transmitter

design. Only in an industrial environment does one expect a lot of random noise. A certain measure of noise rejection can be incorporated into the receiver by tuning to respond to only the carrier frequency and keeping the bandwidth fairly low. Also the receiver could be made to be immune to noise to a certain extent by designing it such that it does not respond to noise of a transient nature or of amplitude less than a specific threshold value. A certain amount of redundancy if built into the procedure for transmitting and receiving, would provide some safeguard against noise which is aperiodic in nature.

Owing to reasons stated above and because the AM system offers the advantage of lower set up cost the use of carrier 'ON-OFF' keying seems to be suitable for the application in hand and will be adopted.

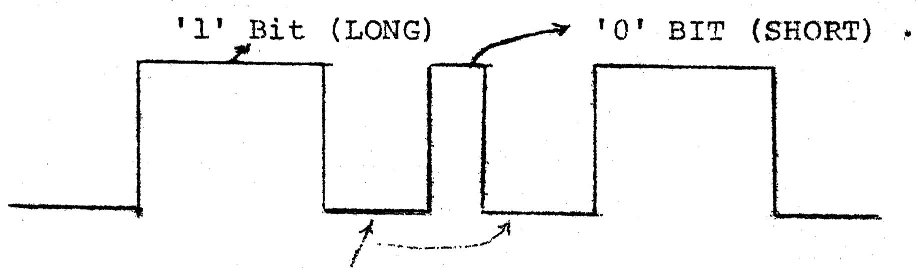
2.6 CODE KEYING TECHNIQUE(6)

There are essentially two methods of keying in a code namely the Return to Neuter keying (RTN) and the Non Return to Zero keying (NRZ). Let us briefly touch upon these methods with a view to effecting a choice. Figure 2 refers to these two methods.

2.6.1 RTN

One may make a design decision that a '0' bit and '1' bit will be of different durations to enable identification. The bits are separated (for timing purposes)

by a brief period of space between each bit.



Timing info. inserted by space between bits

Figure 2(a): FTN Keying

With this method of transmission, the carrier is allowed to return to a neutral (space) condition between each bit. Since mark condition may be treated to signify a '1' and the space a '0', this technique is also some times called Return to Zero Keying (RTZ). The interbit separation should not be mistaken for a '0' bit.

2.6.2 <u>NRZ</u>

The second method of keying is shown in Figure 2(b). This method of keying is to assign a fixed time interval in which to transmit a bit and then to let mark be the binary '1's and the space the binary '0's

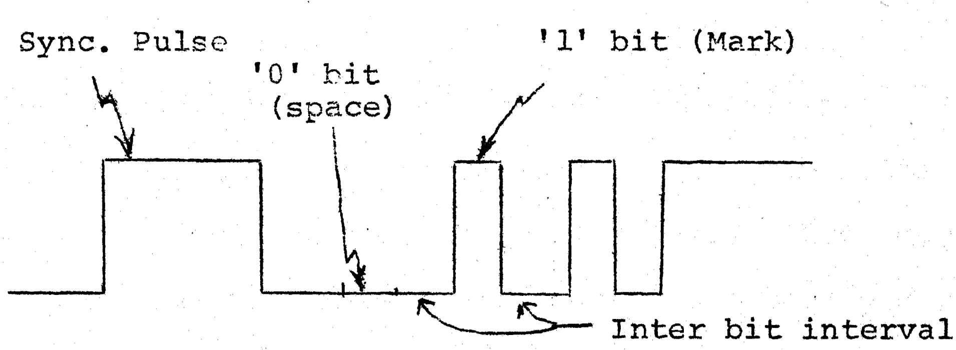


Figure 2(b): NRZ technique.

With this method no inherent synchronisation is assigned to each bit position. As such some receiver technique has to be employed to recognise the bits of the code group. This is done by preceeding a group of bits with a unique and preliminary character such as a long mark to provide the time reference required. This is sometimes called the start of Message (SOM). It is necessary then, to have local receiving timers which are synchronous with the transmitter timer and which look at the incoming signal at each time interval to see if the incoming bit is a '0' or a '1'.

2.6.3 Choice of Code Keying Technique

There are certain advantages and disadvantages with each of the two methods. If it is assumed that the carrier medium can be keyed at some maximum rate (bit rate) then twice as many bits can be transmitted by the NRZ method because there is no need to return to neuter between each bit. However, with NRZ there must be some reliable means of synchronization between the transmitter and the receiver. If the pulse train becomes longer the more stringent are the timing stability requirements. Since synchronous operation is essential, the transmitter and receiver should some how start together. This necessitates a preliminary synchronisation time which reduces to a certain degree the twice as fast speed ratio.

With RTN,bit synchronisation information accompanies each bit and the circuit timing is less critical. Each bit is timed as it is received and the return to neuter between bits is sufficient to tell the receiver that one bit is complete and to prepare for the next bit. As no synchronisation pulses are required this method is also called the synchronous keying.

For a suitable choice one has to look at the overall system he has in mind. If both transmitter and receiver are operating continuously from a reference time, the RTZ method can be used. However, this technique involves generation of pulses of two different widths and inserting these in their respective places (in the time domain) in a serially transmitted code group. At the receiver means must exist for pulse width discrimination before the code is understood. Hardware wise it will be involved.

With the other method the transmitter and receiver need not be ON always. The receiver may be made live by the long synchronising mark pulse and a local clock may then start up and scan the line at predetermined intervals of time to check if a '0' or a '1' bit is received. After code transmission both transmitter and receiver may shut off. This technique is simpler in use, offers reduced complexity in hardware realisation and affords saving of power during non operate periods. This method therefore seems suitable and will be adopted.

2.7 POWER LEVELS

The service area being small and the receivers being operated within the near field of the transmitting loop, it is expected that the power level of the transmitter would be rather low and of the order of a few hundred milliwatts. If so necessary the magnetic field strength could be augmented by using more than one turn of the transmitting loop, individual turns being so positioned that the phase of the current is such that the magnetic field is additive. The magnetic field strength varies directly as the current flowing into the loop. The power needed in the loop depends upon the sensitivity of the receiver for any given area of space. By making the receiver most sensitive the transmitted power could be reduced and vice versa.

2.8 NOISE AND INTERFERENCE (6,7)

It is well known that carrier to noise ratio required for a specific grade of service in a given radio system is dependant upon the characteristics of the noise as well as the modulation and demodulation techniques employed. In the present system where selective signalling is the prime criterion, degradation of voice signal due to noise does not merit consideration. One has to worry only about the distortion of the binary bits and the immunity of receiver to this distortion in making a right decision. As we have chosen the NRZ technique of keying

-in the code, there could be tendancy for inversion of bits in the presence of impulse noise. There are chances that a '0' will be received when a '1' was transmitted or a '1' is accepted when a '0' was actually transmitted. There is no tendency to pick up or drop bits for the receiver is looking at the line only at these instants when it expects a bit to be there. This can be overcome by introducing certain redundancy in the procedure for transmitting and receiving as also keeping a certain threshold at the receiver.

The prime sources of interference are of two types namely natural and man made. The natural sources are lightning, atmospheric static and thermal noise. Man made interference may be due to capacitive-and inductive coupling from power lines, sources of RF energy etc.

The system in question is to be used in a restricted area and practically as an inplant selective signalling service. Besides loop length is not very large. Hence greater significance has to be attached to interference due to undesirable coupling from man made sources rather than atmospherics etc. The inductive fields generated by power lines can induce relatively large signals in the transmitter loop. Open wire lines are particuarly susceptible. This kind of interference is eliminated by tuning the transmitter and receiver antennas to the carrier frequency thereby rejecting the low power

frequency or its harmonics.

RF energy sources (predominant in industrial establishments) have a broad spectrum and as such may cause interference. This could be avoided by having a fiarly low bandwidth, and a reasonable receiver threshold.

While talking of interference, consideration has to be given to likely effects the designed system will have on adjoining systems like telephone service, commercial broadcast receivers and other wireless communication links of the same frequency. The telephone system is a balanced (with respect to ground) two wire system and any coupling would cancel out. Commercial broadcasting frequency spectrum starts from 525 kc/s upwards and the carrier frequency in question of a few tens of KHz is not likely to cause any adverse reception. The radiated power from the loop will be so negligibly small at distances comparable to the wave length of the carrier frequency that it will not cause any interference to other communication links operating in the same frequency range.

2.9 BANDWIDTH

The limitation if any comes from consideration of only noise rather than due to other factors like adjacent channel interference, speed of transmission, acceptable distortion etc. The transmitting antenna being

an open wire loop its Q will be fairly small thereby making the BW large. At the frequency of operation of say 80 KHZ with an assumed value of Q = 10, the BW would be 8 KHZ which is adequate. The speed of transmission in this application is not high and hence does not directly influence BW considerations. On the receiver side by using a loop antenna with a low loss ferromagnetic core, a fairly high Q and consequentl a narrower bandwidth and good selectivity can be achieved.

2.10 SYNCHRONISATION

There are several techniques to achieve synchronous operation of transmitter and receiver. The sync information could be originated at the transmitter itself as in TV for example. A second method is to have two separate clocks one each in Transmitter and receiver running independently from a given reference time. This requires that the clocks be extremely stable once started and continue to run in synchronisation with no external aid. Such a method is preferred when both transmitter and receiver are continuously 'ON'. Any instability in the clocks would have cumulative effect. A third method is to use the sync techniques of the teleprinter system which is essentially an intermittant and a start-stop type of system. There are two clocks one in transmitter and other in receiver. A transition from mark to space in the transmitter condition (preceded by a start of Message (SOM) pulse) starts up the receiver

clock which goes through a single cycle of finite number of steps depending on the predetermined number of characters in a word length. During this one cycle the receiver scans the line at periodic intervals to check if a '0' or a '1' is received. On completion of one cycle the receiver clock ceases and remains waiting at the starting point until another mark to space transition is received.
The effect of instability in the clocks is limited to one cycle of finite number of steps only and hence the error is not cumulative. Thus the necessity of having extremely stable clocks is dispensed with and it affords a certain amount of flexibility in designing receiver line sampling mechanism. Due to reasons of simplicity of operation the last method of synchronisation is adopted for the present application.

2.11 Having decided upon the various techniques to be adopted in the system, next chapter is devoted to lining up of subsystems which when put together will be capable of operating in the required manner as an integrated system.

CHAPTER 3

SUBSYSTEMS LINEUP

3.1 Before embarking on actual circuit design it is always desirable to finalise the line up of subsystems keeping in view the overall performance requirement of the integrated system. When once this is done, the exercise of designing can be undertaken so as to fulfill the functional requirements of each subsystem block. Such an approach would facilitate fixing up of the design criteria to be employed for each block of the system.

3.2 FUNCTIONAL REQUIREMENTS OF THE OVERALL SYSTEM

From a central control, on transmitting a desired model a command signal should originate in the selected receiver which may be used for paging or remote control. If it is meant for paging the command signal could be used for alerting the owner of the receiver by means of a beeping sound. In remote control applications the command signal could be suitably used for actuating a mechanism. On termination of the transmission of a fixed duration the receivers should be either automatically or manually

reset to be in readiness for the next call. This is a one way signalling system only, with no facility to talk back or retransmission from the receiver in response to the command. In paging applications it is desirable that -

(a) The receiver be miniature in size for ease of carrying

(b) the battery drain be kept low

(c) facility be provided for passing of verbal message to the selected addressee after alerting him.

The transmit-receive procedure should have certain redundancy so that the chances of wrong address selection is minimised. Let us now see how these requirements can be met.

3.3 TRANSMITTER

The block diagram is shown in Figure 3. The functional description of various blocks is as under.

3.3.1 Code Setting Mechanism

This provides a means for address selection. As speed of transmission is not important serial transmission of code is enough. The code setting mechanism should enable the operator to write-in the necessary binary code. This mechanism could be a conventional telephone dial which produces a number of pulses depending upon the decimal digit dialled. Although this appears more

attractive to adopt due to its common usage for long, in this particular application it may not be used for the reason that the processing of the telephone dial output for transformation to the binary code involves a lot of digital circuitry as interface. A simpler approach is to have a number of two position switches which can be set ON or OFF according to the binary code chosen. The obvious advantage of the telephone dial system is that the address representation in decimal system is far more compact than the corresponding binary code and is more easily remembered than a long string of 1's and 0's. But when the number of addresses are reasonably small (say about a 100) as in the present application there is hardly any advantage to be gained by the use of telephone dial. Also one is apt to think that setting a number of switches is far more time consuming than dialling a few numbers. On the contrary, in the dialling system, all the digits of an address have to be dialled every time. Whereas with the code setting switches only a few switches may require to be changed at a time to obtain a new address. The probability that all the switches have to be changed at any one time is rather very low.

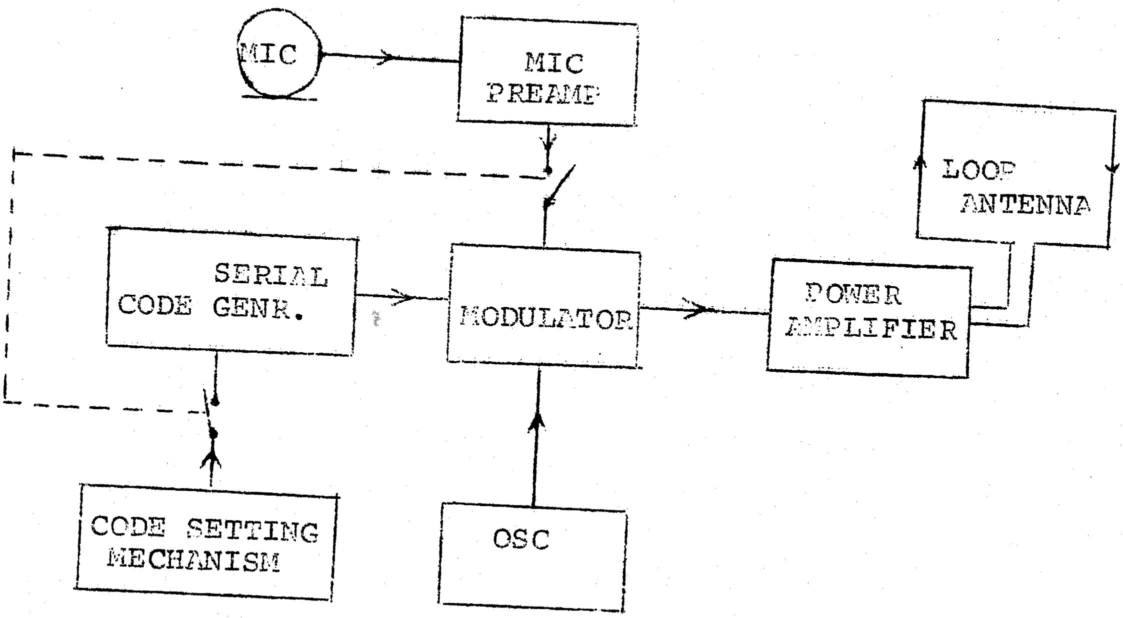


Figure 3: Transmitter

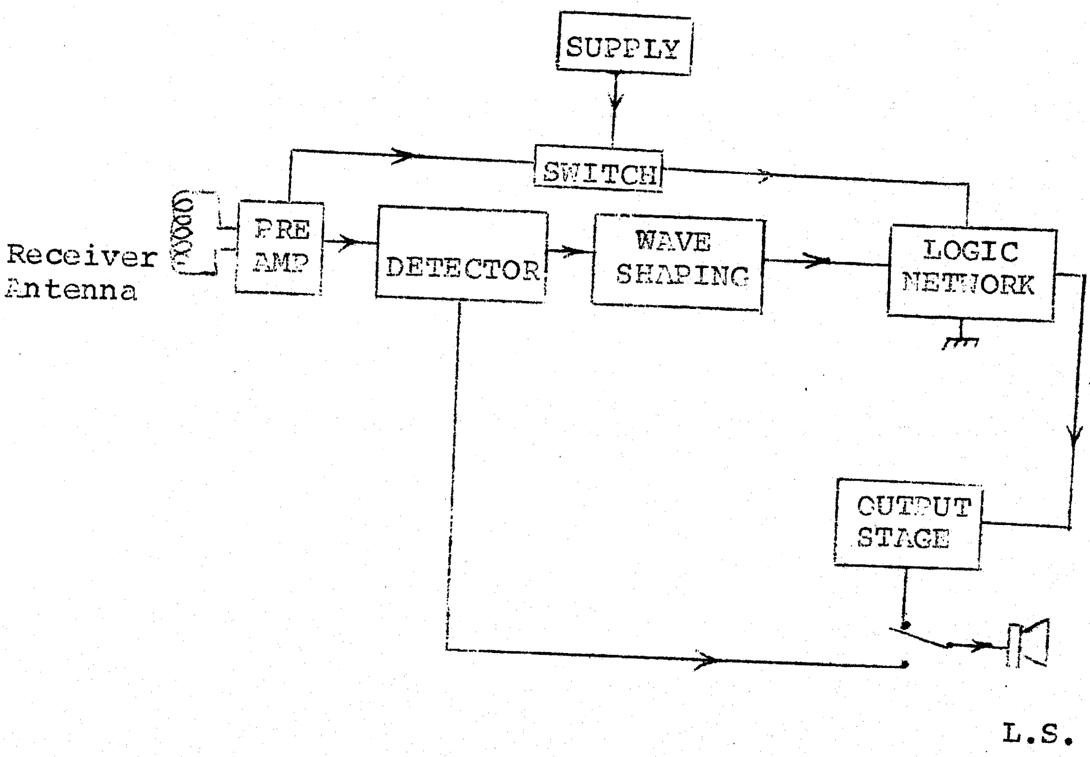


Figure 4: Receiver

3.3.2 Serial Code Generator

This has to perform the following

(a) Once the code is set by the operator, it should generate the corresponding serial binary code, the 0's and 1's being represented by the presence or absence of a unipolar pulse.

(b) As redundancy is desired in the transmit-receiver procedure the code group should be repeatedly generated at periodic intervals for as long as desired by the operator.

(c) The code generator has to prefix each code group by a long SOM or sync. pulse.

To achieve the above functions, some form of memory is required which can remember the code for repetitive transmission. Solid state digital shift registers can be used for this purpose. Because of their versatile performance and small size IC shift registers are ideal for the application in hand. Dual flip flops are available in one chip which can be connected up as a shift ~~shift~~ register of the required number of bits. Into this shift register information could be entered directly from the code setting switches and the bits drawn out in a serial fashion. Parallel in - serial out shift registers can also be used instead of separate flip flops

to reduce the IC count. For shifting of the bits entered into the shift register, clock pulses are necessary and generation of these should be an integral part of the code generator. Through use of appropriate gating the SOM pulse can also be prefixed with the code group.

3.3.3 Modulator

The output of the serial code generator is in the form of unipolar pulses. As it has been decided to use the carrier ON-OFF keying, the job of the modulator is to suppress the carrier for a '0' bit of the binary code and let the carrier through for a '1' bit. A single transistor configuration acting as a gate would suffice for this switching job. The input binary code will be the gating signal and the carrier the gated one. As we are only interested in the presence or absence of carrier, the modulator need only be rudimentary and undue design criteria need not be given over its efficient performance. As already mentioned, in paging applications it may be desirable to have facility for transmission of a message. So the modulator besides acting as a switch, should also be able to use the voice frequency input from the mic amplifier and modulate the carrier. The same switching configuration of the modulator can be used.

In this case it will act as a chopper modulator. Here again the design criteria need not be critical because high fidelity performance is not required.

3.3.4 Power Amplifier

It should be such that it can fulfill the following requirements -

(a) The amount of current flowing into the loop decides the magnetic field intensity being directly related to it. Hence the power amplifier should be capable of giving sufficient current gain.

(b) It should be able to drive the series tuned loop antenna which has a low d.c. resistance.

(c) Output configuration should be such that it should facilitate use of loops of different lengths and hence of slightly different values of d.c. resistance.

(d) Fidelity requirements are not stringent.

3.3.5 Loop Antenna

Though its physical length might be large, it is otherwise a small antenna because its overall length is kept at a small fraction of the wave length. The guage of wire chosen depends upon the length of the loop to be used because of d.c. resistance consideration. The

series tuned loop will practically present an impedance equal to the d.c. resistance of the loop of wire across the output terminals of the power amplifier. Hence, once the length is decided an appropriate guage of wire should be chosen such that the power amplifier is capable of driving the resultant d.c. resistance. Tables supplied by manufacturers are available which indicate the resistance of wire per KM length for various guages. The current and voltage ratings should also be borne in mind.

The wire could be bare conductors of aluminium or copper which are varnished. Multistrand conductors could also be used. The length of the loop being fairly large, provision of adequate mechanical strength has to be kept in view. PVC insulated multistrand copper conductors are also suitable but are slightly more lossy as compared to bare conductors because of capacitive effects of insulation. Inside a building the loop may be concealed in wall mouldings, under a large rug or taped to the walls or ceiling. For outside use the wire can be supported on insulators on posts or just simply strung (off the ground) around the area. The actual configuration depends upon the location. The wire should be insulated from metal surfaces.

3.4 RECIEVER

Block schematic is shown in Figure 4. The functional description of various blocks is as under -

3.4.1 Receiver Antenna

The receiver being for LF reception of a few tens of kilohertz the antenna has to be very long. However these days low loss high permeability ferromagnetic cores suitable for operation from 1 HZ to 1000 KHZ are available. By use of such a material for the receiver antenna core its size can be made to be within manageable limits. A suitable ratio of length over diameter of the core should be chosen as the increase in flux linkage by the use of core material is dependant upon it. The induced voltage in the antenna coil will be maximum when the axis of the ferromagnetic core is perpendicular to the plane of the transmitting antenna. That is the flux lines will be along the axis of the receiver antenna core material. By a priori knowledge of the configuration of the transmitting antenna, the receiver antenna could be kept properly oriented for best reception. For remote control purposes in many applications the receivers are likely to be kept stationary and as such the receiver antennas could be kept properly oriented. In paging applications the receiver locations are not deterministic except for a knowledge the general area in which they operate. Depending upon whether the transmitting loop is

is in the horizontal or vertical plane, the receiver antenna core could be fixed to stay vertical or horizontal by suitable support so that it remains perpendicular to the plane of the transmitting antenna when carried by a person in his pocket.

Core materials are available in assorted shapes and sizes. By a proper choice, this bulky hardware item could be made to occupy a reasonably small space in a miniature pocket receiver. To restrict the bandwidth and selectivity, tuning of the receiver antenna is essential. The ferrite core antenna is the most compact antenna for the minimum loss.

3.4.2 Preamplifier

Its main function is to boost up the voltage level of the input signal received from the tuned input circuit for purposes of further processing. A secondary role is that of a sentry. To conserve the standing drain on the battery (particularly in paging application), it is imperative that during idle periods between calls, the receiver should consume as little power as possible. On receipt of a transmitted signal the receiver sentry can automatically switch on power supply to the rest of the receiver for processing the incoming signal.

The transmitted power level requirements depends upon the receiver sensitivity. However the receiver

gain should not be made so large that its operation is adversely affected by noise or by instability. Suitable feedback techniques may be needed to make the amplifier stable and also match its input to the essentially low impedance of the receiver antenna.

3.4.3 Detector

This is a conventional envelope detector which extracts the intelligence (binary code or voice) after rejecting the carrier. Diode detectors have a certain minimum cut in voltage and forward drop. This may not be desirable for weak signal reception. A transistor detector may be suitable for this purpose because it gives a certain gain besides acting as a detector. By use of this, for voice signal reception we may not need an audio amplifier to feed the earphone or loudspeaker thereby saving additional hardware.

3.4.4 Switch

The job of this is to switch the power supply to the logic network of the receiver (which consumes maximum current), only after the reception of a signal from the preamplifier. Miniature relays can be used because of their excellent isolation properties. However indigenously their availability is scarce. In the absence of miniature relays, the switching could be affected electronically by use of solid state devices like thyristors and

transistors. Use of thyristors can be precluded in paging application because it cannot switch off by itself unless extra hardware is incprorated. Every time a selective call is transmitted all the receivers will have to come on and process the signal to check for code correspondance. Only that receiver which is selected will give an aural or visual indication to its owner who can perhaps manually reset the receiver so that the thyristor is cut off. Others would not even know about it and hence will not be able to switch off the extra power consuption. Hence an automatic means of switching ON and OFF is indicated which can be accomplished by a transistor circuit.

3.4.5 Wave Shaping Unit

The role of this is to -

(a) reshape the detected binary code

(b) produce an output signal which is compatible for processing by the succeeding digital logic network.

This block will essentially be made up of a Schimitt trigger which can be an IC chip or constructed out of discrete devices.

3.4.6 Logic Network

The role of this is to accept the incoming data which is in a serial fashion, convert it into a parallel form, check for code matching and generate an output signal

in case of code correspondance. To perform the functions this block will consist of a shift register, a clock pulse generator for shifting bits and a decoder. Besides, a few gates will also be required. While the logic network could be constructed out of discrete devices, it may be preferrable to use ICs for this purpose, owing mainly due to reduction in circuitry thereby enabling miniaturisation of receiver. Suitable ICs are available indigeneously also.

3.4.7 Output Stage

This is only for accepting the output signal of the logic network for purposes of suitably modifying it to drive the loud speaker or a prime mover. A multivibrator or an UJT oscillator could be used which can drive the loudspeaker to produce a beeping sound for alerting the owner of the receiver. In remote control applications it may take on a variety of shapes depending upon the use to which the signal will be put to.

3.4.8 Power Supply(7)

A mention of this is made because of its importance in paging applications where the need is for a small receiver. Its size and capacity are subjective matters in remote control applications. A variety of battery types as mentioned below could be used.

(a) Zinc Carbon

(b) Alkaline

(c) Mercury

(d) Nickel Cadmium.

Except for nickel cadmium none of the above batteries are suitable for recharging. The alkaline and mercury batteries provide longer life before discharge whereas nickel cadmium, ~~after~~ by repeated recharges, provides the longest overall life.

The minimum power supply life according to international standards is one day. One day of life is defined as 8 hours of operation with a duty cycle of 6 sec receive at rated audio power output, 6 sec transmit at rated RF power output and 48 sec standby. Rechargeable batteries normally provide several days of life, while non-rechargeable batteries provide upto 3 weeks of life. The most economical type of battery is dependant upon both the type of operation and the battery cost per hour.

CHAPTER 4

TRASMITTER -DESIGN CONSIDERATIONS AND FUNCTIONAL DESCRIPTION

4.1 The choice of hardware to be used in designing the system was strongly influenced by a desired to use only indigenous components. While for linear circuits a variety of both the active (only discrete) and passive elements are indigenously available, as far as the logic is concerned the choice was perforce restricted to use of TTL gates. Normally TTL gates are used for high speed applications in the nanosecond region. However they are equally capable of performing at lower speeds also as in this particular application. SN 7400 series of TTL gates are now being standardised in this country and are available commercially. The logic used in both the transmitter and receiver incorporate TTL gates.

The speed of bit transmission need not be high in this present case. As the binary bits are used to modulate the carrier, we should ensure that during each ON period, a number of cycles of the carrier go through. Keying at audio rate has been chosen arbitrarily to be 250 cycles per sec. This will ensure that even at the lowest frequency of operation which may be say 25 KHz, envelope distortion will not be severe.

4.2 CODE GENERATOR

A block diagram of the code generator is shown in Figure 5. Figure 6 shows the interconnection of each of the 6 DPDT switches which are used for writing-in of the desired binary code into the shift register. There are two astable multivibrators and a 6 bit shift register. Each astable multivibrator uses two NAND gates with necessary timing resistors and capacitors. The 6 bit shift register is made up of 3 IC chips, each of which contains 2 D type edge triggered flip flops. Instead of 3 separate chips, only one chip with a 8 bit shift register with parallel in serial out facility could have been used. However it is not indigeneously marketted as of now.

4.2.1 Astable Multivibrator operation using TTL NAND gates

The astable multivibrator circuit is shown in Figure 7. Let us assume that to start with R_1 is returned to logical '1'. As R_2 is grounded input 4 sits at logical '0'. With this as the starting point the following truth table is derived which depicts the initial stable state condition.

	GATE 1			GATE 2		
Pin	1	2	3	4	5	6
	1	1	0	0	0	1

So long as R_1 is at logical '1' the above is true and hence one is certain about the starting state of the astable. If now R_1 is returned to logical '0', capacitor C_1

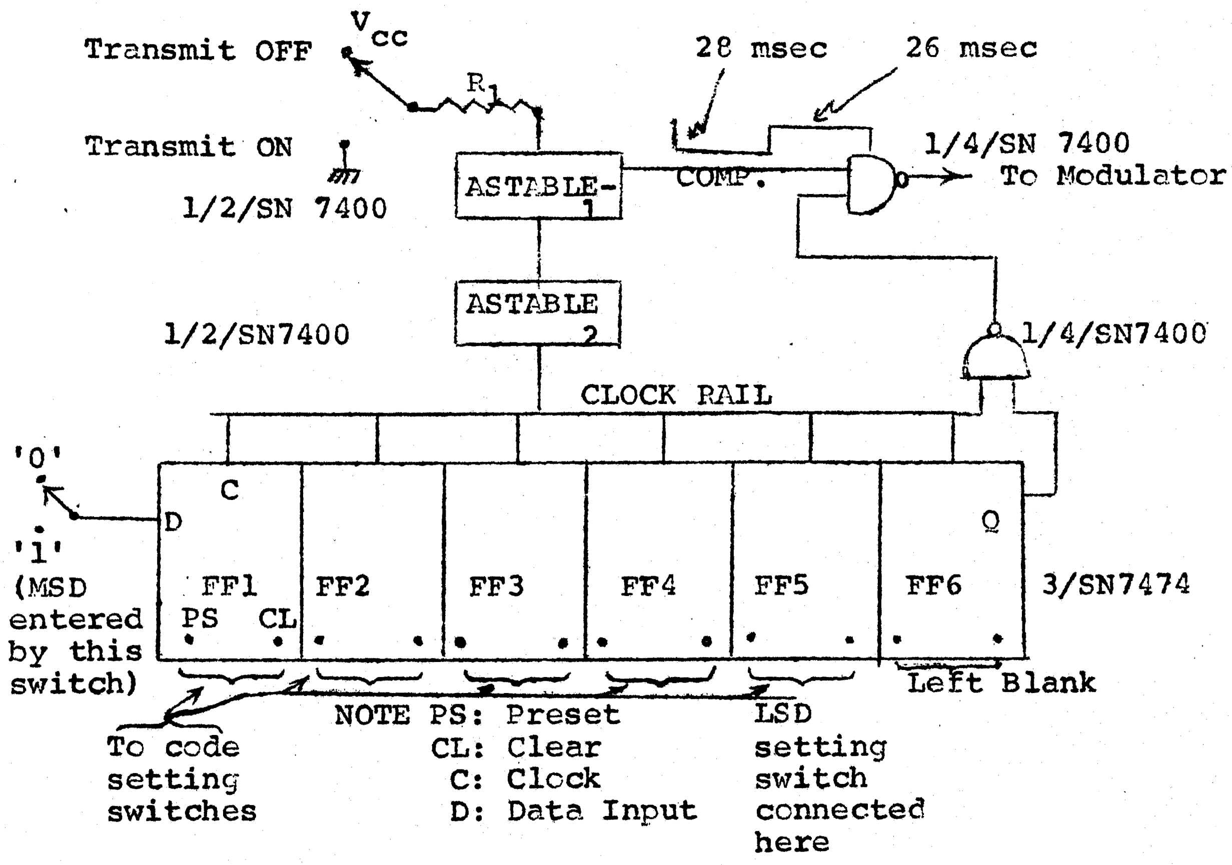


Figure 5: 6 Bit Serial Binary Code Generator

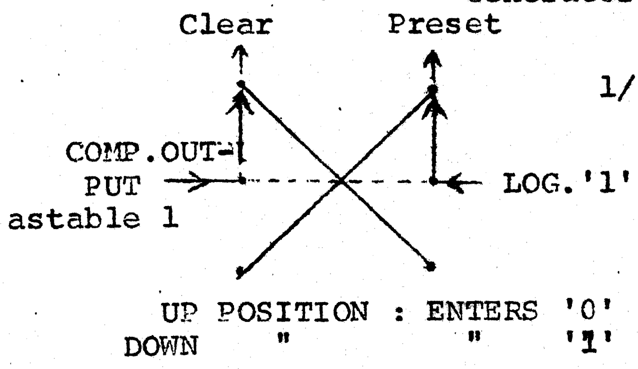


Figure 6: Code Setting Switch inter-connection

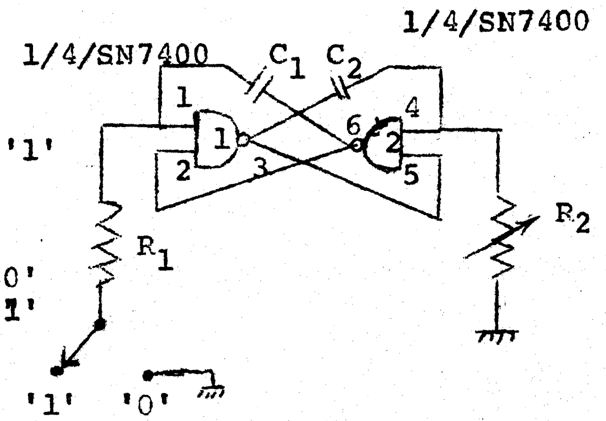


Figure 7: Astable Multivibrator Configuration Using TTL NAND Gates

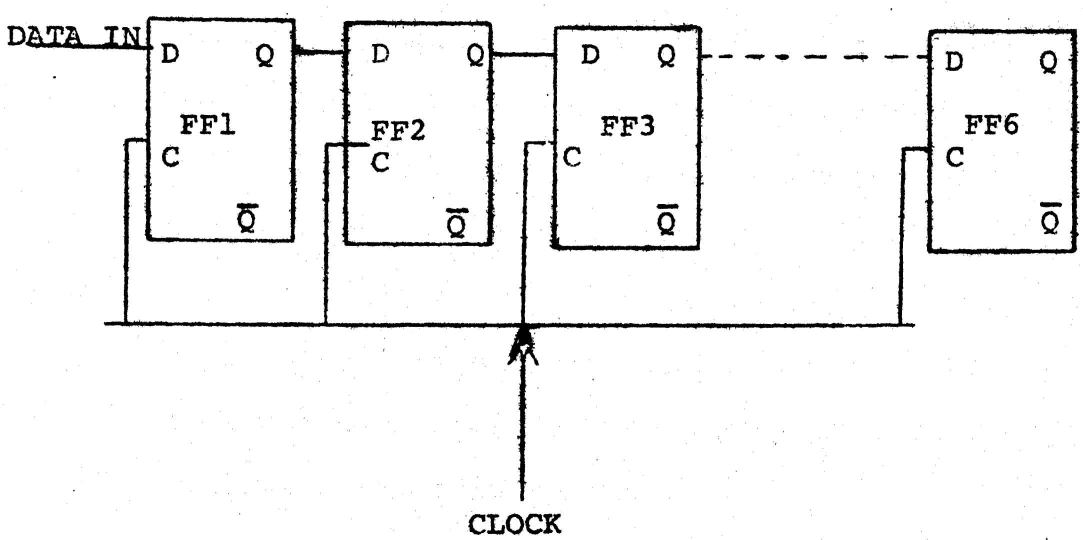


Figure 8: D type Flip Flops used as shift registers.

starts to slowly discharge and Pin No. 1 of gate 1 starts to fall towards '0'. When it reaches the input threshold of about 1.5 volts (property of TTL), transition occurs and hence the output of gate 1 goes high. Capacitor C_2 being not capable of accepting a transient, the sudden transition at the output of gate 1 appears at input pin 4 of gate 2. The output of gate 2 thus goes to zero because the other input 5 is shorted to the output of gate 1. Now C_2 commences to charge up slowly and hence the voltage at pin 4 of gate 2 tends towards logical zero. On reaching the threshold, gate 2 fires and its output goes high. This process repeats over and over again. Due to positive feedback we thus achieve an astable action.

The code generator has two astable multis. When no code is to be transmitted, resistor R_1 of astable 1 is held at logical '1' level. The normally high output of astable 1 under this initial condition is connected to one of the inputs of astable 2. Hence both astables remain in ~~s~~table states as defined by the truth table. The astable 1 has been adjusted to give an 'ON' period of 28 m secs and an 'OFF' period of 26 m secs (the reason for this unequal periods is for ensuring reliable synchronisation to be explained later in the chapter devoted to receiver). If now R_1 is returned to logical '0' level astable 1 starts oscillating. During its off period,

astable 2 oscillates giving out 'ON-OFF' pulses of 2 m sec duration each. The off period of astable 1 is 26 m secs and hence during this period the astable 2 will go high 7 times each for 2 m secs and go low 6 times of the same duration each. The timing diagram in Figure 9 shows these waveforms. The pulses of astable 2 are used as clock for shift register.

For a 6 bit shift register we need a minimum of 6 flip flops. Three IC chips each of which containing two of D type positive edge triggered flip flops are used. Figure 8 shows the interconnection diagram when these flips flops are used in the shift register mode(15). The truth table for asynchronous operation of the flip flops is as under

Preset	Clear	Q	$\bar{Q}$
0	0	1	1
1	0	0	1
1	1	Q	$\bar{Q}$
0	1	1	0

Observing from row four of the truth table we note that information can be clocked into the flip flops through the preset input when the clear rail is kept high. This fact is made use of in the following manner to write-in the required code into the shift register.

There are six code setting switches of the DPDT variety connected one per flip flop. The terminals of the switches are connected as shown in Figure 6. The switches corresponding to bit positions which are to be made '1' are put down. The up positions stand for '0'. When a particular code setting switch is in '1' position, the preset line is connected to the complementary output of astable 1. The clear line goes to logical '1'. When astable 1 output goes low, the preset line becomes logical '0'. From truth table we can see that Q output of that particular flip flop become 1. There is no change in the status of the flip flop when the preset line goes high.

The clock pulses are generated by astable 2 when the output of astable 1 goes low. These clock pulses shift the information entered into the flip flops from left to right.

It will be noted from Figure 5 that the code setting switches are off-set to the left by one position i.e. the first switch from the left is not connected to the preset line of flip flop 1 but to its data input. This is done to obviate the shifting of the last bit out of the shift register with the first clock. It will be observed that the + edge of the clock is used to shift the bits in the shift register and during each clock period the bit appearing at Q output of last flip flop

of the shift register is sensed by the NAND gate 4. If there is no off-set in setting the code, with the arrival of the first clock pulse (+ edge) the information in the shift register would be moved to the right by one bit and what would be sensed by NAND A during the first clock period would be the least significant bit but one, the LS bit having been shifted out with the first clock + edge.

The output of the shift register is connected to a NAND gate (A) whose other input is given to the clock. The next NAND gate (B) has at its two inputs the output of A and and the complementary output of astable 1. The purpose of these NAND gates is for prefixing the SOM or the syne pulse before each code group.

Looking at the timing diagram, the complementary output of astable 1 remains low for a period of 28 m sec high output from NAND B. This is our SOM pulse. Next during the off period of astable 1, clock pulses shift the contents of the shift register out and they successively appear at the input of NAND A. If the shifted bit is a '0', output of A goes high and that of B low (the other input to NAND B is the complementary output of astable 1 which during this period of clocking stands high). Likewise if a '1' bit is shifted, the output of NAND B goes high. Thus whatever is the bit shifted out of the shift register it appears at the output of NAND B. Thus by the addition of these two NAND gates we are able to prefix the SOM pulse before the code group.

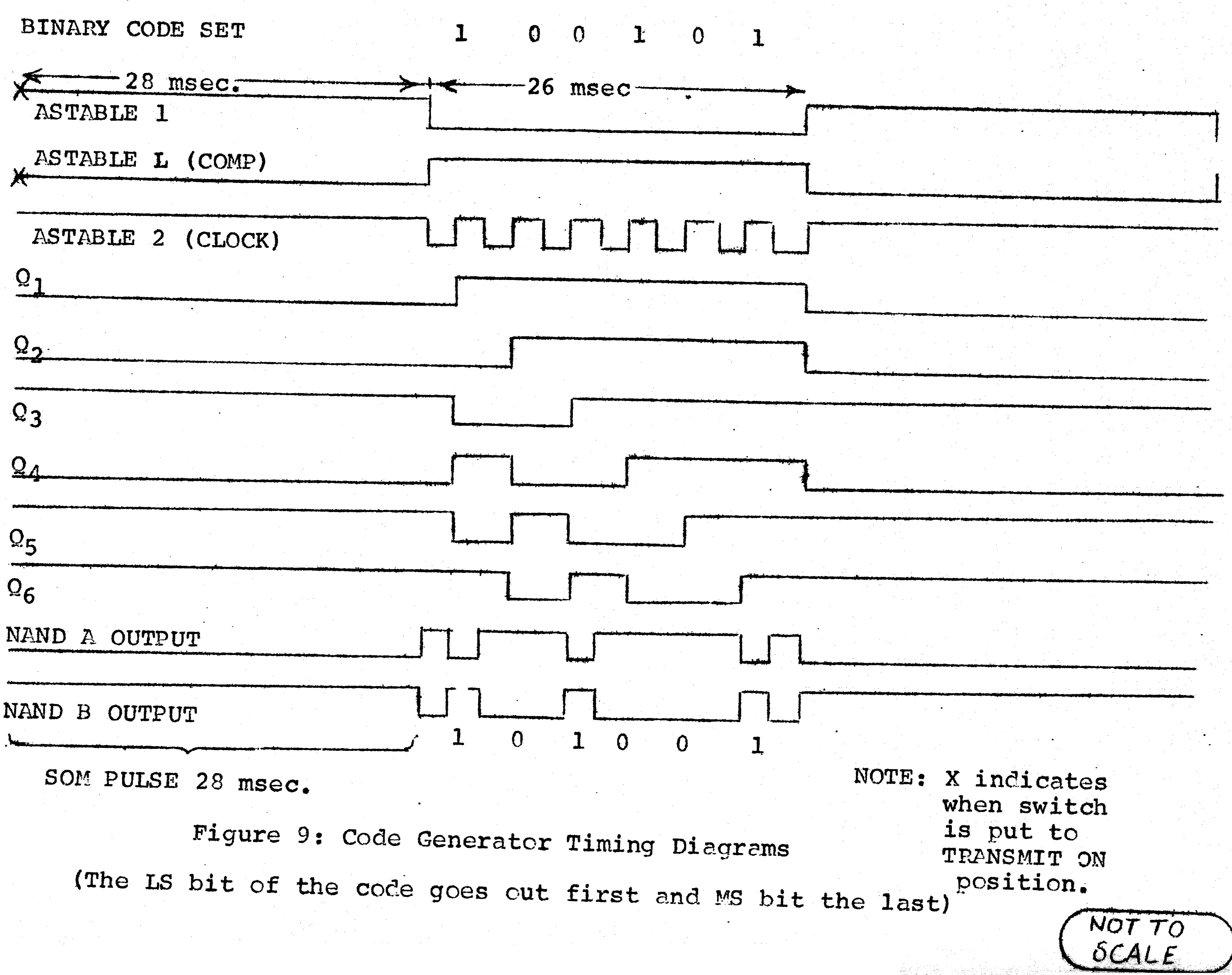


Figure 9: Code Generator Timing Diagrams

(The LS bit of the code goes out first and MS bit the last)

So long as the resistor R_1 is kept returned to logical '0', the preset code group gets shifted out repeatedly and at the output of NAND B we have a repetitive waveform of the code group with the SOM pulse prefixed. So whenever a particular code group is to be transmitted the code is set by the operator using the selector switches and the switch associated with resistor R_1 is flipped over to logical '0' position (i.e. Transmit ON position). To stop transmission the switch is returned to logical '1' position (which is Transmit OFF position).

4.3 OSCILLATOR

Within reasonable limits, the stability and distortion of the carrier are not very vital factors for the present application. Any type of oscillator which can satisfactorily operate in the frequency region under consideration would suffice. A colpitt's type of oscillator was used to generate the carrier. The circuit is shown in Figure 10. 7

6

4.4 CARRIER 'ON-OFF' KEYING (10)

7

6

Configuration used is shown in Figure 11. This is a conventional sampling gate. R_1 and R_2 are summing resistors. The carrier is the gated signal and the binary code output from the code generator is the gating signal. When the control voltage is at its lower level the transistor is biassed below cut off. When the control

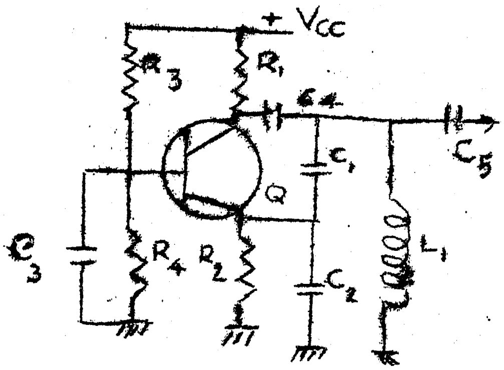


Fig: 10 Colpitts OSC

($R_1 = 390\Omega$ $C_1 = 0.1\ \mu f$
$R_2 = 200\Omega$ $C_2 = 0.3$ "
$R_3 = 3.9\ K\Omega$ $C_3 = .02$ "
$R_4 = 620\Omega$ $C_4 = .02$ "
$L_1 = .048\ mH$ $C_5 = .02$ ")
Q: CIL521

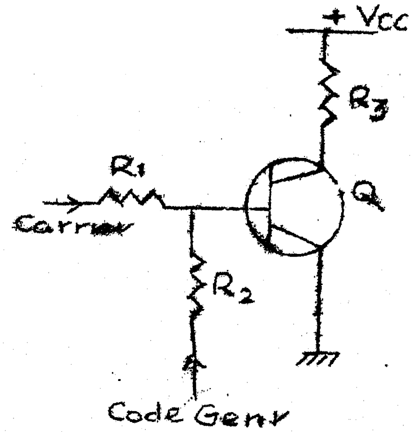


Fig: 11 Modulator

(Q : CIL 521
$R_1 = 6.8\ K\Omega$
$R_2 =$ "
$R_3 = 2\ K\Omega$)

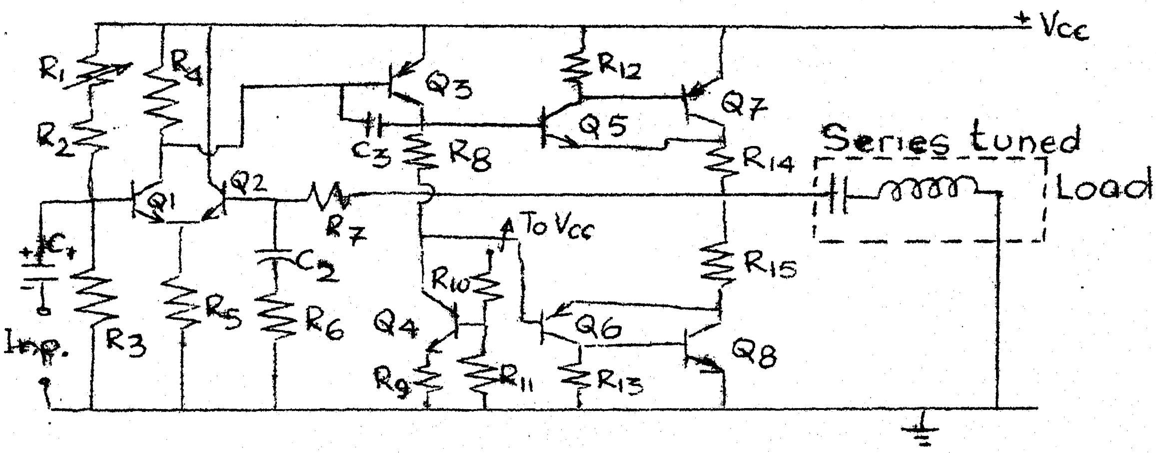


Figure 12: Power Amplifier

- R_1 = 3.3K
- R_2 = 18K
- R_3 = 20K
- R_4 = 680 ohms
- R_5 = 3.9K
- R_6 = 470 Ohms
- R_7 = 10K
- R_8 = 120 ohms
- R_9 = 200 ohms
- R_{10} = 9.1K
- R_{11} = 1K
- R_{12} = 220 ohms

- R_{13} = 220 ohms
- R_{14} = .47 ohms
- R_{15} = .47 ohms
- C_1 = 10 mfd
- C_2 = 4 mfd
- C_3 = 50 pf
- Q_1 = CIL 521
- Q_2 = CIL 521
- Q_3 = SF 103
- Q_4 = SG 103
- Q_5 = SL 100
- Q_6 = SK 100

- Q_7 = ECP 055
- Q_8 = ECN 055

voltage reaches its upper level, the bias brings the transistor out of cut off and into the active region. So long as the gate persists the transistor will sample the signal voltage which will then appear amplified at the output.

For reasons of simplicity the same configuration was used to modulate the carrier by voice signal for transmission of verbal messages which may be required in paging applications. In this role the circuit acts as a chopper modulator. Although this scheme of voice modulating the carrier is not very efficient, owing to the fact that fidelity is not a dominant consideration in this application, it was felt sufficient to use the same circuit without increasing the hardware.

4.5 POWER AMPLIFIER

The circuit diagram is shown in Figure 12. A complementary symmetry output configuration was chosen because there is no need for an output transformer. At the frequency of operation in the system which is well above audio range, conventional transformers are not efficient because of excessive losses. The transformer has to be specially designed using ferrite cores. Besides, class B operation with complementary symmetry output has certain advantages like low standing current, low device dissipation and high efficiency.

The circuit gives adequate current gain to drive the series tuned loop antenna at its output. At resonance the load impedance presented is practically the d.c. resistance of the loop which is of the order of a few ohms. The circuit can drive loads ranging from 2 to 10 ohms. The driver is biassed at a relatively high IQ so that the output stage can drive upto 4 sumps peak into a low impedance load.

4.6 LOOP ANTENNA AND THE FIELD INTENSITY (12,13)

Given below is a discussion on the approach adopted and the actual derivation of the magnetic field intensity in the near vicinity of a rectangular loop antenna.

When a current I flows in a closed circuit a magnetic field intensity H at any point in space results. For computational purposes it is convenient to consider the total magnetic intensity at any point as the sum of the contributions from elemental lengths ds of the circuit each carrying a current I. The quantity Ids is called a current element. It is a vector quantity having the direction of the current. By Ampere's law one can find the total magnetic intensity H at any point P in space due to a current carrying conductor as the sum or integration of the contributions from all the current elements of the circuit and that

$$H = \oint \frac{Ids \quad \mu r}{4 \pi r^2}$$

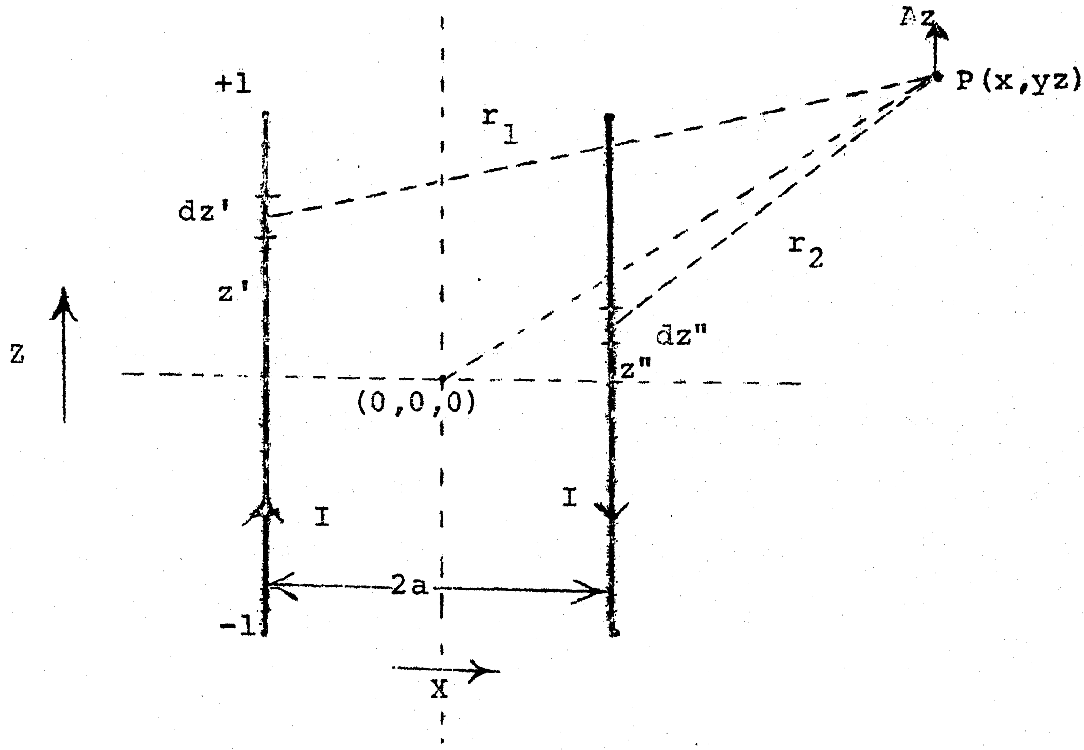


Figure 13: Vector potential due to the two parallel conductors in Z direction.

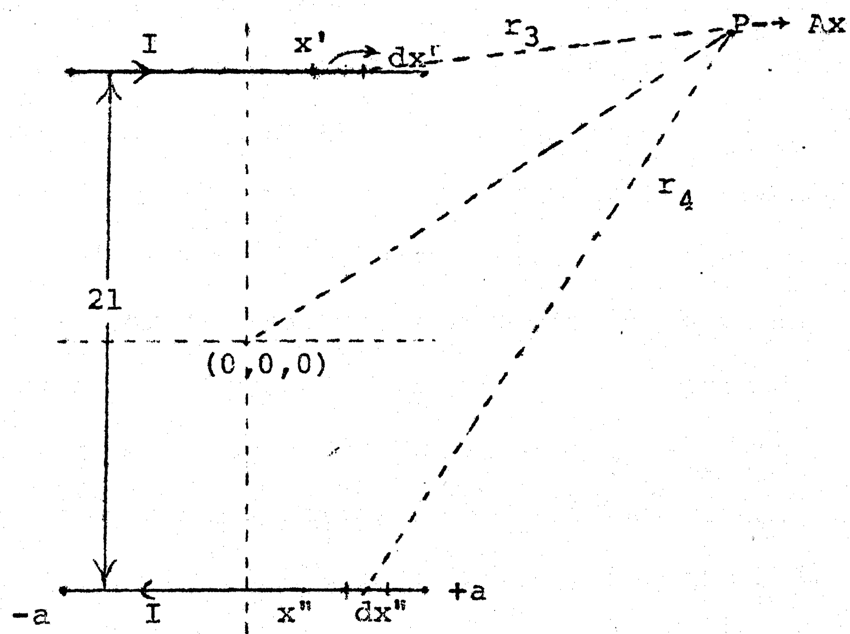


Figure 14: Vector potential due to the two parallel conductors in X direction.

where r is the distance of the point P from the elemental conductor and μ_r is a unit vector in the r direction.

In the present case the antenna consists of 4 sides and may be either a rectangle or square in shape. The four conductors are treated to be lying in the same plane.

The approach adopted is to evaluate the magnetic vector potential, the space derivative of which gives the magnetic intensity H. The two are related by H = curl A.

The general expression for vector potential is given by

$$A = \int_v \frac{i\,dv}{4\pi r}$$

where i is the current density, the integration being done over the volume in which the current density exists. We can consider the loop antenna as consisting of 4 long straight wires of finite lengths carrying inphase current. We shall consider each of the two pairs of parallel conductors at a time to evaluate the vector potential.

Referring to Figure 13 let one pair of parallel conductors of the loop be of length $2l$ and lying in XZ plane. Separation between conductors is $2a$ (i.e. the length of the other two sides of the rectangle). Let the origin be at the centre of the loop. The current in the two conductors are in phase but flow in opposite directions.

We have

$$r_1 = \sqrt{(x+a)^2 + y^2 + (z-z')^2}$$

$$r_2 = \sqrt{(x-a)^2 + y^2 + (z-z'')^2}$$

The current is entirely in the z direction so that the vector potential Az has only one component in the Z direction. This Az is the resultant of the individual vector potentials Az_1 and Az_2 due to the two conductors.

$$Az_1 = \frac{I}{4\pi} \int_{-1}^{+1} \frac{dz'}{r_1}$$

$$= \frac{I}{4\pi} \int_{-1}^{+1} \frac{dz'}{\sqrt{(x+a)^2 + y^2 + (z-z')^2}}$$

Let $p = z - z'$ limits $p_1 = z - 1$

$dp = -dz'$ $\qquad p_2 = z + 1.$

$$\therefore \quad Az_1 = \frac{I}{4\pi} \int_{z+1}^{z-1} \frac{-dp}{\sqrt{(x+a)^2+y^2+p^2}}$$

$$= \frac{I}{4\pi} \int_{z-1}^{z+1} \frac{dp}{\sqrt{(x+a)^2+y^2+p^2}}$$

$$= \frac{I}{4\pi} \ln \frac{(z+1) + \sqrt{(x+a)^2+y^2+(z+1)^2}}{(z-1) + \sqrt{(x+a)^2+y^2+(z-1)^2}} \tag{1}$$

Likewise

$$Az_2 = \frac{-I}{4\pi} \int_{-1}^{1} \frac{dz''}{r_2}$$

$$= \frac{I}{4\pi} \ln \frac{(z-1) + \sqrt{(x+a)^2 + y^2 + (z-1)^2}}{(z+1) + \sqrt{(x-a)^2 + y^2 + (z+1)^2}} \tag{2}$$

$$Az = Az_1 + Az_2$$

$$= \frac{I}{4\pi} \ln \frac{[(z-1) + \sqrt{(x-a)^2+y^2+(z-1)^2}][(z+1) + \sqrt{(x+a)^2+y^2+(z+1)^2}]}{[(z+1)+\sqrt{(x-a)^2+y^2+(z+1)^2}][(z-1)+\sqrt{(x+a)^2+y^2+(z-1)^2}]} \tag{3}$$

$$Ay = 0 \quad \text{and} \quad Ax = 0.$$

Therefore

$$\left.\begin{aligned} Hx &= \text{Curl}_x\, A = \frac{\partial}{\partial y} Az - \frac{\partial}{\partial z} Ay = \frac{\partial}{\partial y} Az \\ Hy &= \text{curl}_y\, A = \frac{\partial}{\partial z} Ax - \frac{\partial}{\partial x} Az = \frac{-\partial}{\partial x} Az \\ Hz &= \text{curl}_z\, A = \frac{\partial Ay}{\partial x} - \frac{\partial}{\partial y} Ax = 0 \end{aligned}\right| \tag{4}$$

We consider the other pair of conductors now. Figure 14 refers

$$r_3 = \sqrt{(x-x')^2 + y^2 + (z-1)^2}$$

$$r_4 = \sqrt{(x-x'')^2+y^2+(z+1)^2}$$

The vector potential exists only in the x direction Proceeding as earlier we get

$$Ax_1 = \frac{I}{4\pi} \ln \frac{(x+a) + \sqrt{(x+a)^2+y^2+(z-1)^2}}{(x-a) + \sqrt{(x-a)^2+y^2+(z-1)^2}} \tag{5}$$

and
$$Ax_2 = \frac{I}{4\pi} \ln \frac{(x-a) + \sqrt{(x-a)^2+y^2+(x+1)^2}}{(x+a) + \sqrt{(x+a)^2+y^2+(z+1)^2}} \tag{6}$$

$$Ax = Ax_1 + Ax_2 . \quad Ay = 0 \quad Az = 0.$$

$$\left.\begin{aligned} Hx &= \mathrm{curl}_x A = \frac{\partial}{\partial Y} Az - \frac{\partial}{\partial z} Ay = 0 \\ Hy &= \mathrm{Curl}_y\ A = \frac{\partial}{\partial z} Ax \\ Hz &= \mathrm{Curl}_z\ A = \frac{-\partial}{\partial Y} Ax \end{aligned}\right| \tag{7}$$

It is noted that the Hy term is present in the end results of both the pairs of conductors described by the sets of equations (4) and (7).

$$\text{Resultant field intensity } H = \sqrt{H_x{}^2 + (Hy_1 + Hy_2)^2 + Hz^2} \tag{8}$$

Equation (8) describes the expression for the resultant field intensity. The values of Hx, Hy_1, Hy_2 and Hz are to be substituted in this. These values can be obtained by taking partial derivatives of Ax, Ay and Az (calculated from (1), (2), (5), (6)) and substituting in the groups of expressions (4) and (7). It is obvious that it is cumbersome to write the expression for H as a single equation. However

by rearranging the expressions into a neater form, a program has been written for evaluating the value of H at any point in space for a loop of any given dimension carrying a certain current I. The listing of the program is attached as Appendix 'A'.

Results were computed for various loop diemensions carrying various currents and the general pattern of the distribution of the field intensity both inside and to a certain distance outside the loop on a number of planes parallel to the plane of the loop in the Y direction was plotted to gain a better insight. The field intensity plots are shown in Figures 15 and 16.

In the plane of the loop as we proceed along the diagonal (figure 15) starting from the centre towards one corner of the loop, the magnetic field intensity keeps on increasing gradually at first and rapidly later until it reaches infinity exactly at the corner. This is so because right at that point the distance from the conductor is zero and the intensity being inversely proportional to the distance of the point, it shoots upto infinity (or to a very great value tending to infinity if we consider the point to be at a finite distance from the centre of the conductor). Outside the loop there is a steep fall and at distances comparable to the diemensions of the loop the intensity tends almost to zero. On planes parallel to the plane of the conductor

the behaviour is same except that at the corner the intensity has a finite value because the distance of the point is finite in the Y direction.

In the other plot at Figure 16, the intensity variation along a line parallel to one of the conductors is plotted. Again the intensity shoots upto a very large value tending to infinity as we approach a conductor from the centre. In a parallel plane above or below, the intensity variation is similar but of lower values at each corresponding point. Outside the loop, the decay is very rapid.

The rate of change of intensity as we proceed along the diagonal is greater as compared to along a line parallel to one of the conductors. This stands to reason because when we proceed along the diagonal, the intensity vairation is influenced by both the conductors to the left and right whereas along a parallel line, we keep at a finite distance from one conductor always whose influence is constant while only the influence due to the other conductor varies.

As we proceed in Y direction vertically above or below the centre from the plane of the loop the intensity gradually diminishes. In the plane of the loop the intensity is minimum right at the centre. However as we move in the vertical direction, the minimum intensity

point does not fall vertically over the centre of the loop but is confined to the vicinity of the centre line. This is attributable to the bending around of the magnetic flux lines.

EVALUATION OF INDUCTANCE OF LOOP ANTENNA (23)

By knowing the gauge of wire one can find out its diameter and other characteristics from manufacturer's data. With these data it is possible to estimate the inductance of the loop antenna theoretically. For a rectangular loop of wire

$$L = .0092[(a+a_1)\log_{10}\frac{4aa_1}{d_1} - a\log_{10}(a+g) - a_1\log_{10}(a_1+g)]$$

$$+ .004\,[\mu\delta(a+a_1) + 2(g+d/2) - 2(a+a_1)] \qquad (1)$$

and $$x_c = .1071\, d\sqrt{f} \qquad (2)$$

Where a and a_1 are the lengths of the sides in mm

d = diamter in mm

$g = \sqrt{a^2+a_1^2}$ in mm

$\mu \simeq 1$ for copper. L is in microhenries, f is in hertz.

x_c is an argument of which δ is a function.

After finding x_c, by a table look up, given in most of the radio engineer's handbooks, δ can be determined.

As an illustration let f = 80 KHZ, guage of wire = 18 SWG for which d = 1.22 mm. X_c is calculated from (2)

to be 3.68. δ from table look up $\approx$ .18. For one of the experimental rectangular loops of 40 m x 53 meters set up, L is calculated from expression (1) to be equal to 406 μH. From a knowledge of this L, the correct series tuning capacitor required can be calculated. Experimentally the inductance of the loop antenna was found to be 395 μH which is reasonaly close to the theoretical estimation.

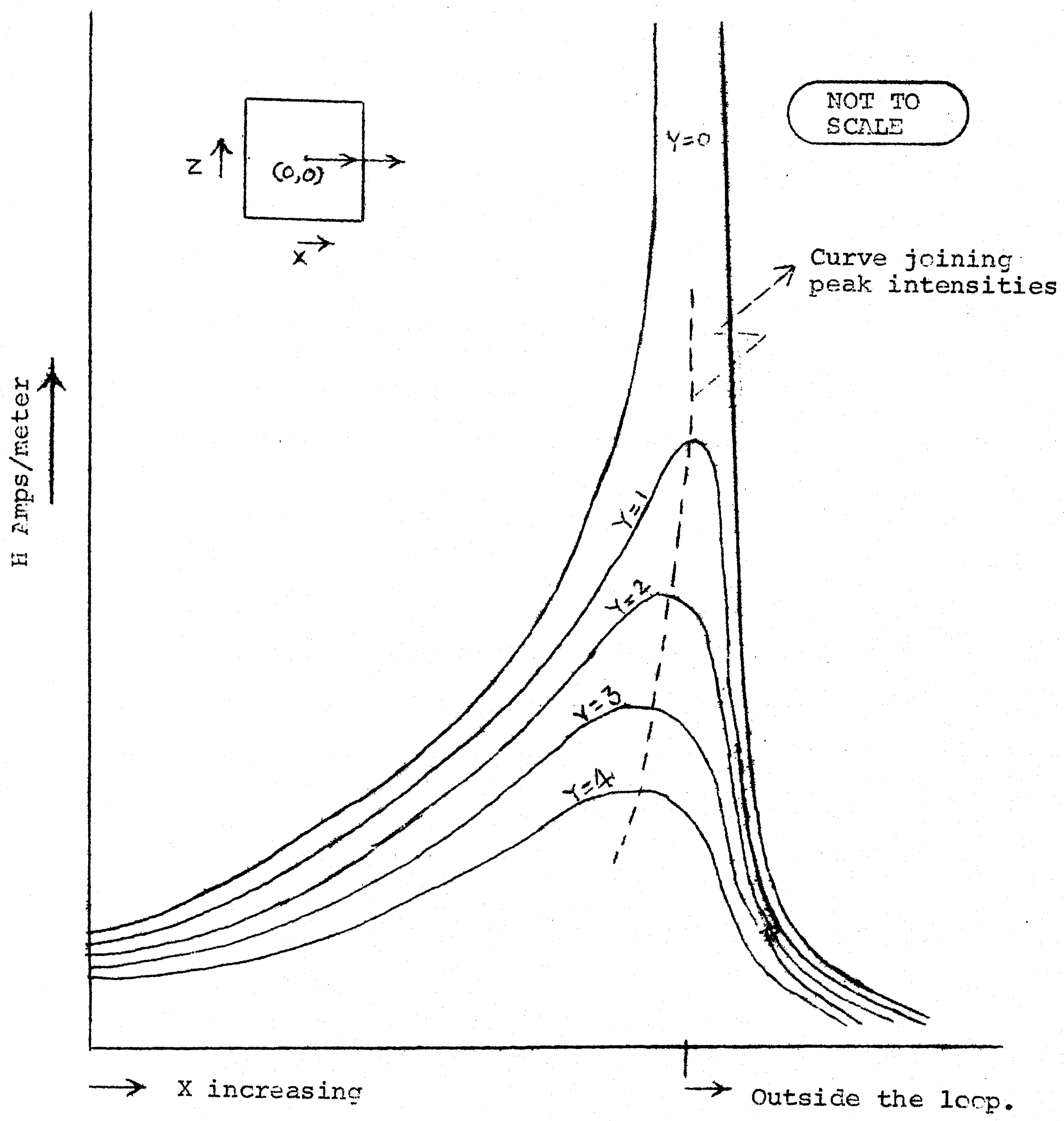


Figure 16: Z is frozen at 0. Plot shows variation of H field along X direction in the positive quadrant. Y values represent parallel planes at unit distances.

CHAPTER 5

DESIGN CONSIDERATIONS : RECEIVER

5.1 The block schematic of the receiver has already been discussed under chapter3. Here we shall see the circuit design of the receiver.

5.2 RECEIVER ANTENNA (11)

In the frequency range of a few tens of KHZ under consideration the receiving loop antennas are very small electrically and are usually magnetic dipoles formed with either air core or iron core loops. These small antennas have advantages including directivity which permits discrimination against undesired frequencies and noise and also in its ability to discriminate against local electrostatic fields. In such cases the current in the loop may be taken to be relatively uniform and one can obtain a simple expression relating output voltage and magnetic field intensity.

For free space or any medium where $\mu = \mu_o$

$$V_{ic} = - i\, 8\pi^2\, 10^{-7}\, f\, H\, A\, n \cos\phi$$

$$\approx 7.9 \times 10^{-6}\, f\, H\, A\, n \cos\phi \qquad (1)$$

where

μ = permeability of the medium

$= 4\pi \times 10^{-7}$ henry/meter for free space

H = magnetic field intensity in amps/meter

f = carrier frequency in HZ

n = No. of turns in coil

A = effective area of the loop in sq. meters

ϕ = angle the flux lines make with the loop axis.

V_{ic} = Induced voltage

For a typical air core loop the effective area is essentially that of the physical area enclosed by the coil itself. With a ferromagnetic core the effective area of the coil becomes

$$A = A \text{ actual} \times \mu'_{core} \qquad (2)$$

μ'_{core} is the increase in field magnetic flux enclosed by the loop when the core is employed. This increase will depend upon the relative permeability of the rod material μ'_m and the length over diameter ratio of the core. The coil self flux increase due to a core is defined as μ'_{coil} where

$$\frac{L_{core}}{L_{air}} = \mu'_{coil}.$$

For an l/d ratio of 12, an emperical relation gives

$$\frac{\mu'_{core}}{\mu'_{coil}} \approx 10.$$

In the experimental receiver an available ferrite core was used with an l/d ratio of 6. The core was meant for commercial broad cast receivers and as such was not the correct choice theoretically for low frequency work. The coil was made up of 100 turns of litz wire with 1.5 cm mean dia and 1 cm thickness. μ' coil measured with a Q meter was 4.

As l/d ratio was only 6, we can adopt as a conservative first approximation a ratio of

$$\frac{\mu'_{core}}{\mu'_{coil}} = 5.$$

This yields $\mu'_{core} = 20$. From this the effective area A can be calculated from equation 2. To calculate the minimum field intensity that should exist for satisfactory receiver operation we proceed as under.

Let us assume a receiver threshold voltage of IV at the output. Knowing the gain, we can obtain the minimum voltage that should be induced in the antenna coil. From this by applying equation (1) we can calculate the value of H required. In the experimental receiver the overall gain was ≈10,000. For IV output, the voltage at its input should be 100μv. As the receiver antenna is tuned the actual voltage appearing across the tuning capacitor will be Q times the induced voltage. The loaded

Q of the coil is 40. Taking these into consideration the actual induced voltage required at the coil works out to 60µv. This is of the same order of sensitivity of commercial receivers. For this induced voltage the magnetic field required can be computed from equation (1), which works out to 270µA/meter. This is the theoretical minimum intensity that should exist within the confined area of space for satisfactory operation of the receiver. The above calculation holds for a carrier frequency of 80 KHZ.

5.3 INPUT COUPLING NETWORK (26)

The tuned antenna circuit has to be coupled to the input of the first stage of the preamplifier. There are a number of coupling network configurations that can be used for matching. Capacitive tapping was preferred because of its simplicity as compared to inductance tapping or a tuned secondary coil. The coupling network taken into use is as shown in Figure 17.

The design expressions for such a configuration are

$$C_1 = \frac{c - c_o}{1 - \sqrt{\frac{c - c_o}{C_T a^2}}}$$

$$C_2 = a\sqrt{C_T(c - c_o)} - c_i$$

where $C = (\omega_o^2 L)^{-1}$ $\quad C_T \triangleq \dfrac{1}{\pi \Delta f R_o}$

$$L_T = \frac{1}{\omega_o^2 \; C_T} .$$

Δf is the 3 db Bandwidth

f_o = resonant frequency

C_T = Capacitance required to get necessary BW when connected in parallel with $R_o/2$.

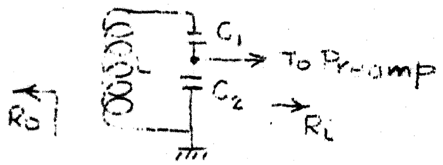
For matching $R_o = R_i \; a^2$ where $a = \sqrt{R_o/R_i}$.

The values of C_1 and C_2 used in the circuit are noted in Figure 12. These values are close to the calculated values using expressions indicated above within reasonable limits.

5.4 PREAMPLIFIER (Figure 13)

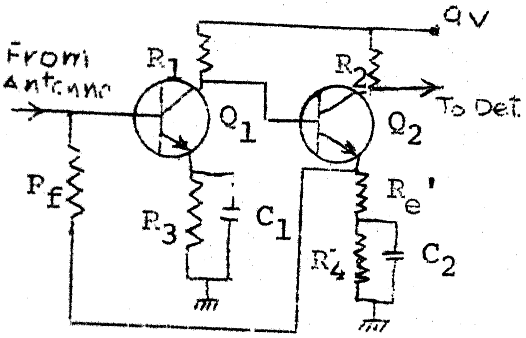
This consists of a two stage amplifier using transistors in the common emitter configuration. It works on a 9V supply. CE configuration was used to obtain sufficient voltage gain. The antenna coil at the input being essentially a current source, low input impedance is desirable for the amplifier stage. This is achieved by current shunt feedback. Further, the resulting low input impedance reduces the possibilities of the existance of a coupling path for positive feedback from some high impedance output point. The voltage gain of the stage is given by

$$A_V = \frac{V_o}{V_s} = \frac{I_o R c_2}{I_s \; R_s} \simeq \frac{R_1}{R_e} \quad \frac{Rc_2}{R_s}$$



C_1 = 1400 pf
C_2 = 36,000 pf
L = 2.5 mh

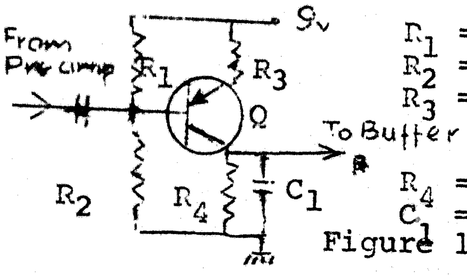
Figure 17: Coupling Network



R_1 = 4.7K
R_2 = 2.7K
R_3 = 330Ω
R_4 = 680Ω
R_f = 20K

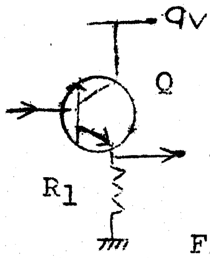
C_1 = 25 mfd
C_2 = 25 mfd
Q_1 = CIL521
Q_2 = CIL 911

Figure 18: Pre-Amplifier



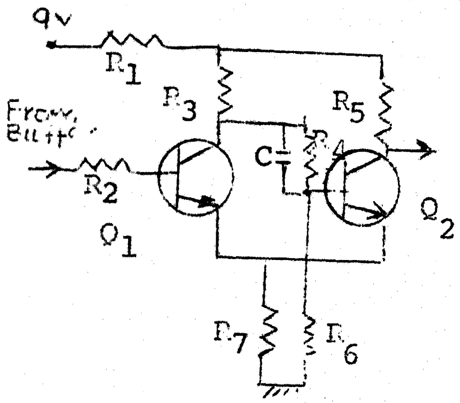
R_1 = 500K
R_2 = 3.3M
R_3 = 100Ω
R_4 = 12K
C_1 = 22000 pf

Figure 19: DETECTOR



R_1 = 3.3K
Q^1 = CIL601

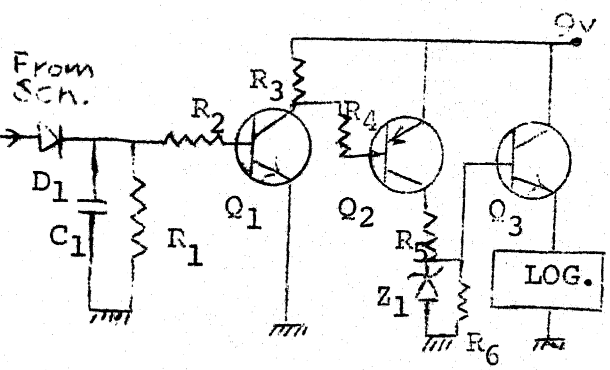
Figure 20: Buffer



R_1 = 1.8K
R_2 = 470Ω
R_3 = 2.2K
R_4 = 22K
R_5 = 2K
R_6 = 6.8K
R_7 = 200Ω

C = 150 pf
Q_1 = CLL711
Q_2 = CIL711

Figure 21: Schmitt Trigger



C_1 = 4µf
R_1 = 22K
R_2 = 20K
R_3 = 9.1K
R_4 = 6.8K
R_5 = 470Ω
R_6 = 20K
Z_1 = 5.6V Zener

Q_1 = CIL611
Q_2 = LFO
Q_3 = SL100

Figure 22: Switch

The gain depends upon stable resistors and is independant of transistor parameters, the temperature or supply voltage variations (8). The overall voltage gain is 9200. Input impedance = 215Ω.

5.5 DETECTOR STAGE (9) (Figure 19)

Instead of using a conventional diode peak envelope detector and amplifying the detected signal, a transistor detector was employed. Detection is done by the diode like characteristics of the base emitter input circuit. For detection performance to be good the transistor should operate at very low quiescent current.

A pnp transistor was used so that we will get the positive going half of the envelope after detection and amplification at the collector of the transistor. The wave shaping unit which follows requires a + going pulse at its input. The gain of the detector was found to be 1 to 5. This is because of operation in the non linear portion of the characteristics.

5.6 BUFFER STAGE (Figure 20)

The conventional wave shaping unit which is a Schmitt trigger has a low input impedance when the input transistor conducts. Hence to avoid loading of detector, a buffer stage was used in between.

5.7 SCHMITT TRIGGER (10)

To make its output compatible with the logic which accepts a 'high' level of 5V, the supply to schmitt trigger is dropped by a series resistor to get 5V from the 9V battery. The output goes high from about 0.5V. TTL gates accept upto 0.8V as the low or logical '0' level. The schmitt trigger has a upper triggering level of 1V. The hysterisis is negligible. The output of schmitt trigger is a train of reshaped pulses. In this application the output is used for further processing by the logic network and also to provide sufficient drive to a transistor switch for turning on the supply to the logic.

5.8 POWER SUPPLY SWITCH

The need to have an automatic switch in the receiver which supplies power to logic circuits only on receiving a signal has already been mentioned. The logic circuits draw nearly 90% of the total current in the receiver and hence the need to save standing drain on the battery. There are six ICs besides the output circuit which in all consume around 100 mA of current. Therefore the transistor which switches power supply to the logic circuits should withstand this much of current. Besides, the power supply to the logic must be between

4.75V to 5.25V for guaranteed operation as specified by the manufacturer. Hence there is a need for switching a regulated power supply.

The circuit diagram of the signal powered switch is shown in Figure 22. Under no signal conditions the schmitt trigger output is low. The base of Q_1 is at zero potential. Hence the transistor is cut off. Q_2 which is a pnp, has at its base the supply voltage and thus remains also cut off. Q_3 is also cut off. On the arrival of the SOM pulse the schmitt output goes high. The peak detector C_1R_1 drives Q_1 into saturation. Collector of Q_1 drops towards ground potential and this saturates Q_2. The zener gets sufficient bias and it keeps the base of Q_3 at the reference voltage of 5.6V. Allowing for base emitter drop of .6 volts, at the emitter of Q_3 we get a regulated 5V supply which is fed to the logic.

Normal standby current in the receiver is about 8mA and the fully switched current at the time of signal reception is 100 mA. Hence the current switching ratio is about 1:12.

5.9 ORGANISATION OF LOGIC IN THE RECEIVER

The receiver logic can be subdivided into three distinct parts depending upon their function namely, the local clock generator, serial to parallel converter and the decoder. The block diagram is shown in Figure 18.

The incoming signal has a SOM pulse of a long duration followed by the 6 bit code group (see Figure 9 of Chapter 4). The SOM pulse and the code group constitute one duty cycle and this is repeated over and over again so long as the transmitter is kept on. The negative edge of the SOM pulse is used for timing reference. This edge triggers a monostable multivibrator in the receiver whose ON-OFF periods are adjusted to be exactly equal to one duty cycle of the received signal i.e. 28 m secs 'ON' and 26 m secs OFF. During the time that the monostable output is high the astable multivibrator does not function. When it goes low, the astable multivibrator oscillates at four times the frequency of incoming code and produces pulses which are subsequently divided by four to be used as clock for the shift register. Once code matching is obtained the output of the decoder goes high which is used suitably for producing an alerting beep or for remote control purposes.

5.10 MONOSTABLE MULTIVIBRATOR

This is the master timing unit of the receiver. Its 'ON-OFF' period is adjusted to be conjoint with the transmitted waveform which enables transmitter and receiver to operate synchronously. The synchronization technique is discussed in the next paragraph.

The monostable multivibrator is made up of two TTL NAND gates, four of which are available on one chip. The interconnection diagram is shown in Figure 14. When supply to logic is switched ON by the received signal, the schmitt output is high for a duration of the SOM pulse which is 28 m secs. Input 4 of gate 2 is at zero level to start with. So the initial condition of the monostable is

	Gate 1			Gate 2		
Pin No.	1	2	3	4	5	6
	1	1	0	0	0	1

When the negative edge of SOM pulse arrives, pin No. 1 of gate 1 goes low and thereby the output of gate 1 goes high. Capacitor C_1 acts as a short circuit for the transient and hence both inputs of gate 2 go high. This results in the output of gate 2 to go low. Meanwhile the capacitor C_1 starts to slowly charge up to logical '1' level and the voltage at pin 4 starts to drop towards logical '0'. When the threshold level at pin 4 is reached gate 2 fires and its output goes high thereby completing one cycle of ON-OFF period. By adjusting the value of time constant of R & C, the ON-OFF period can be suitably chosen.

5.11 TRANSMITTER-RECEIVER SYNCHRONISATION

As stated already the negative edge of the SOM pulse triggers the monostable multivibrator which produces an ON-OFF period to correspond to the duty cycle of the transmitter. It is quite possible that the monostable multivibrator may trigger with one of the negative edges of the incoming code instead of getting locked to the negative edge of the SOM pulse. This is illustrated in the timing diagram of Figure 25. Here it is shown that the monostable multivibrator is triggered by the negative edge of one of the data pulses. When this happens the OFF period of the monostable multivibtator extends into the region of next SOM pulse. The negative edge of the SOM pulse will now definitely trigger the monostable multivibrator and hence the ON-OFF periods will fall into step with that of the received waveform. In the worst case the monostable multivibrator can be triggered by the last data bit. Even then by the same process described above the monostable multivibrator period will fall back into step.

5.12 LOCAL CLOCK GENERATOR

The monostable multivibrator is connected to an astable multivibrator which is adjusted to run at four times the frequency of the incoming data pulses. The method of obtaining an astable action using two TTL NAND gates has already been described under the chapter devoted

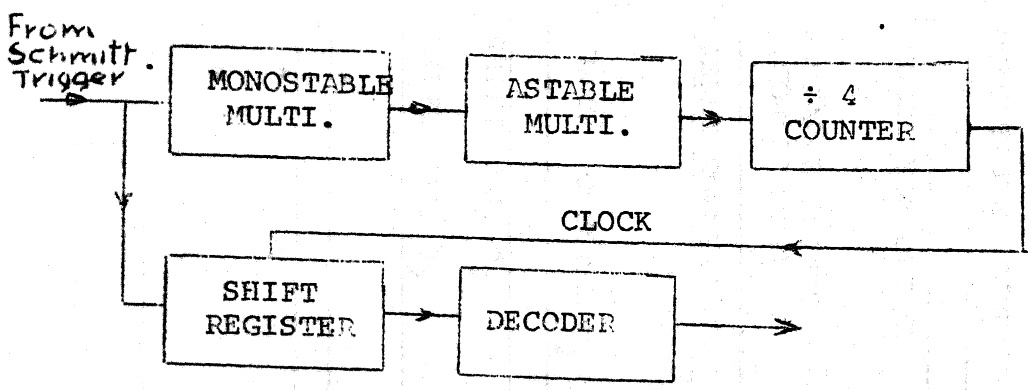
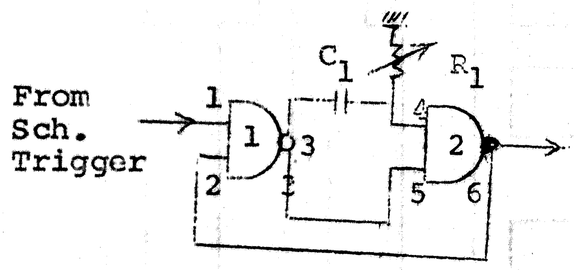


Figure 23: Receiver Logic Organization



R_1 = 2K trim pot
C_1 = 22mfd

Figure 24: Monostable Multivibrator interconnection using TTL NAND gates.

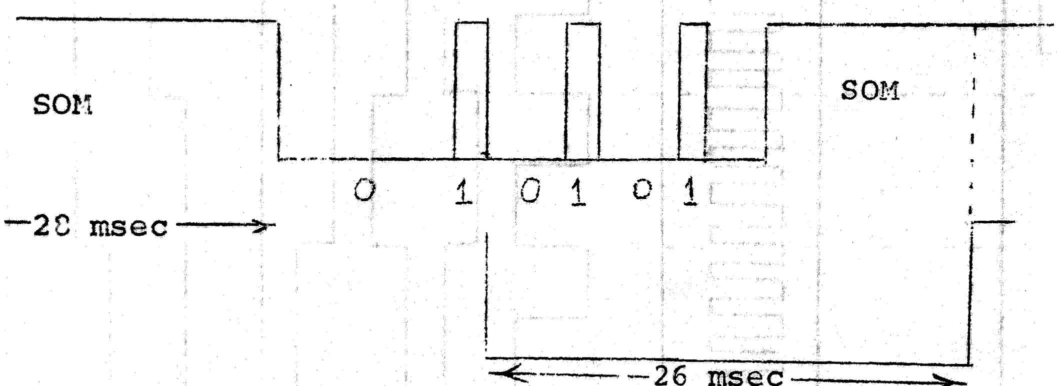


Figure 25: Synchronizing Method

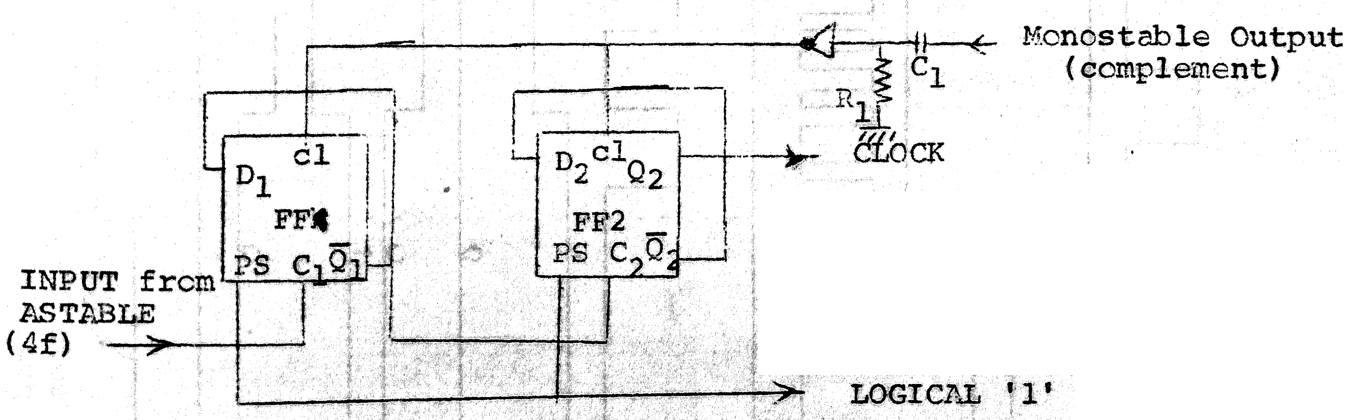
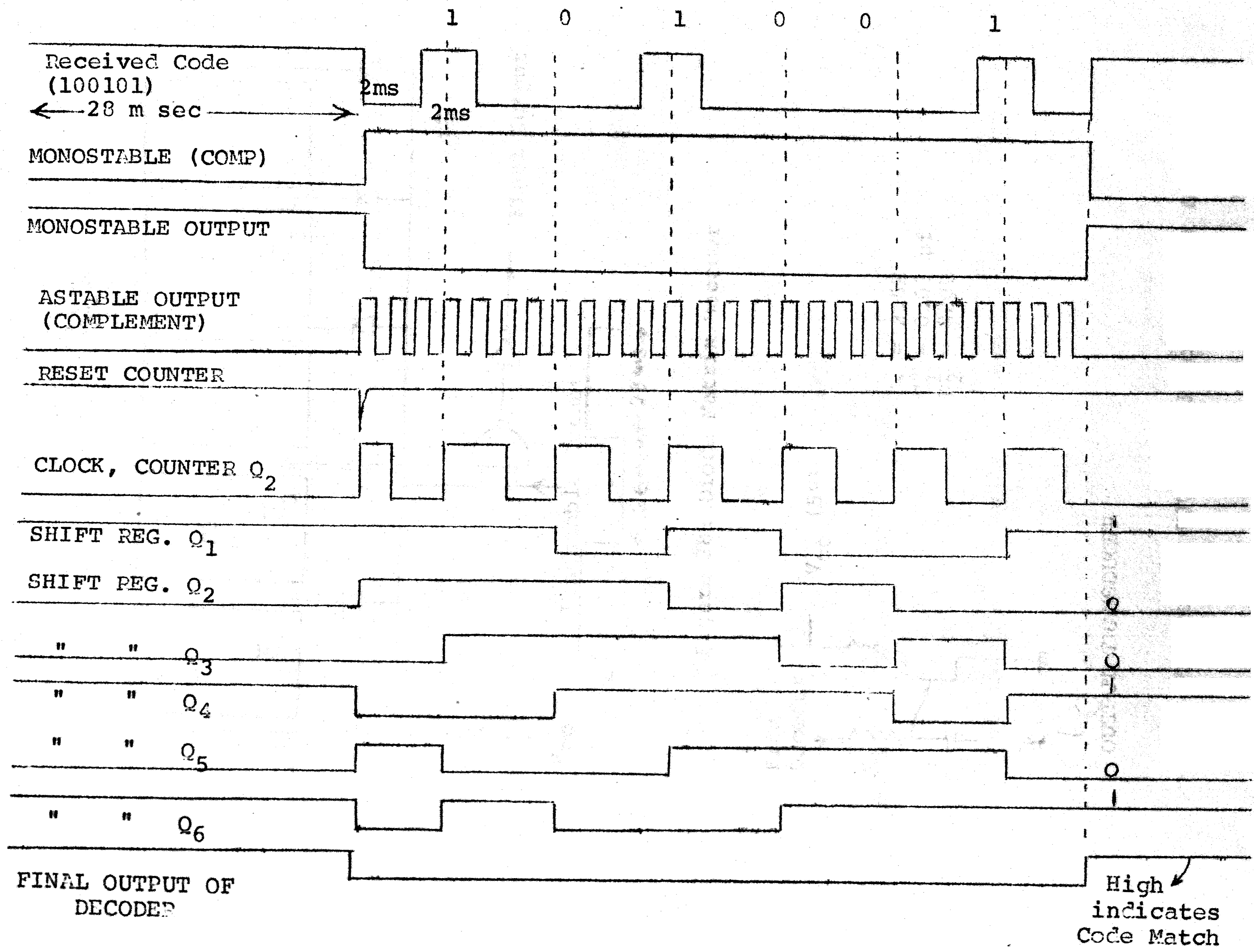


Figure 26: Divide by 4 Counter


1 0 1 0 0 1
Received Code
(100101)
28 m sec
2ms
2ms
MONOSTABLE (COMP)
MONOSTABLE OUTPUT
ASTABLE OUTPUT
(COMPLEMENT)
RESET COUNTER
CLOCK, COUNTER Q2
SHIFT REG. Q1
SHIFT PEG. Q2
" " Q3
" " Q4
" " Q5
" " Q6
FINAL OUTPUT OF DECODER
1
0
0
1
0
1
High indicates Code Match

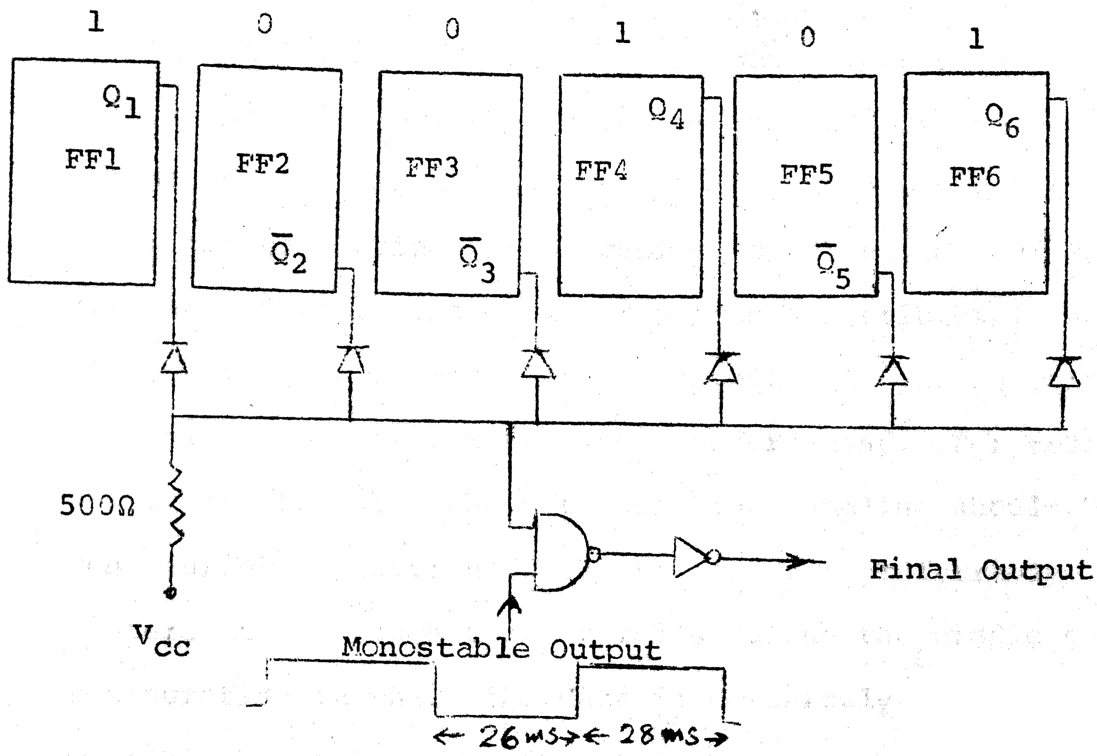


Figure 28: Diode Matrix Decoder

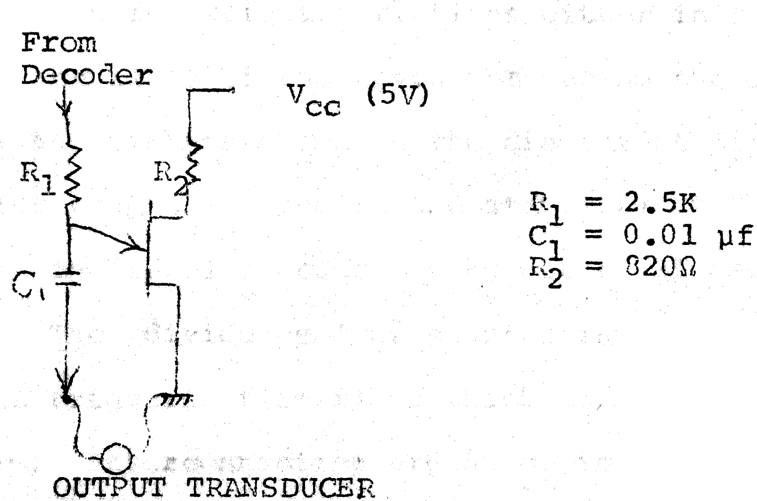


Figure 29: UJT Oscillator (Output Stage)

to transmitter. A counter counts down the output of the astable multivibrator by four and thus produces an output pulse for every four fed at its input. The counter output is used as the clock pulse for the shift register. The rationale behind this technique of counting down for purposes of clock generation requires a little explanation. The rate of arrival of data bits and the duration for which they persist are known before hand. For reliability of accessing the data the line sampling should be done during a fraction of the time period preferrably centered to lie such that it falls during the middle of the duration in which the data is definitely existing. Smaller the fraction better it is because the sampling interval would still lie within the span of the data bit even for slight variations either in the data or in the stability of the device producing the sampling pulses. For the timings shown in the diagram at Figure 27, the worst case tolerance in the stability of transmitter wave form and receiver clock works out to 2% each.

The divide by four counter is made up of two D type edge triggered flip flops which are available on one IC chip. Interconnection are shown in Figure 26. Referring to the truth table of the flip flop given earlier, with preset at logical '1' and clear rail at logical '0', $\overline{Q}_1$ stands high. This is the starting condition. As $\overline{Q}_1$

and D are connected, with the arrival of the first pulse at the clock input C_1, the logical '1' level present at D_1 is entered into FF1. Until the next pulse arrives at C_1 input this condition holds. When the next clock pulse to FF1 occurs, the flip flop changes state and remains so till the arrival of third pulse. We see that the output $\bar{Q}_1$ of FF1 gives a positive going edge with every alternate input pulse which is nothing but division by 2. FF2 is similar in action and divides further by 2. The output of FF2 gives one positive going edge for every four similar edges of the output of the astable multivibrator. The clear line of the counter is triggered by a sharp negative going pulse derived by differentiating the complementary output of the monostable and inverting it. Clearing of the counter is done before the commencement of next cycle. Receiver timing diagram at Figure 27 shows all the necessary waveforms

5.13 SERIAL TO PARALLEL CONVERSION

The incoming code is in a serial fashion and it has to be converted into a parallel form for the purpose of decoding. This involves memory. The shift register is made up of 6 D type edge triggered flip flops. Interconnection diagram of the shift register is the same as used in the transmitter and shown in Figure 8. Here the preset and clear lines are returned to logical '1'. The output of schmitt trigger is fed to the data input of the

first flip flop. During the 6 clock pulses periods, the data is shifted and is available in a parallel form from the respective Q outputs of the flip flops.

5.14 DECODER (Figure 23)

Each receiver has its individual address (preset code) according to which the diode matrix is connected. The connection diagram for an arbitrary code 100101 is shown in Figure 23. If there is a code match the diode matrix output line stays high because all diodes will be non-conducting, their anodes and cathodes being at the same potential. Even if one bit does not match, the corresponding diode gets forward biassed and conducts heavily thereby clamping the output line at logical '0' level. The final output from the diode matrix is derived through a NAND and an inverter gate as shown in the Figure. The purpose of the NAND gate is to inhibit decoding action when bits are in the process of being shifted in the shift register. The monostable multivibrator output waveform is used as the inhibiting signal. During its 'OFF' period the clock pulses shift the bits into the shift register and during the following 'ON' period, code correspondence is indicated by the decoder. The output of the inverter will go high only if matching takes place. As the received code group is repetitive in nature being received at nearly 20 times a second, the final output will also go high at the same rate if matching takes place every time.

5.15 <u>OUTPUT UNIT (9)</u>

This is the final stage of the receiver. The signal obtained from the decoder which indicates code matching has to be used for alerting the owner of the receiver or for actuating a mechanism for remote control. The circuit employed for producing an alerting tone is shown in Figure 29. It consists of an UJT oscillator feeding a loudspeaker or a headphone. The output from the decoder is given to its emitter resistor. Whenever the decoder output goes high the oscillator drives the output transducer producing a beeping sound. The 2KHZ oscillator tone is interrupted for 26 msecs each, 20 times a second thereby producing the beeping effect.

For reliability it is usual to incorporate certain redundancy to safeguard against receipt of false alerts. One method is to count the number of times matching takes place and trigger the output unit only when a certain arbitrarily fixed number is exceeded. The counting may be done either digitally or by analog means.

In the present case the system works like this. The paging call will be continuous series of beeps duration of which is dependant upon the duration of transmission. Even if an unselected receiver gives out an occasional beep due to circuit malfunction the owner of the receiver will not take cognizance of it. While this is

sufficient for paging applications, for remote control where no human element is involved, it is imperative to introduce redundancy as mentioned in the last paragraph.

5.16 RECEIVING VOICE MESSAGES

This will be by prior understanding. The operator, will transmit the selective signal for a fixed duration which may be chosen arbitrarily to be say 15 or 20 secs. The selected receiver will give the alerting tone for the same duration. On cessation of this tone, the owner of the receiver has to flip a switch in the receiver and be ready for the voice message. The operator immediately after cutting off code transmission can use the mike and transmit the voice message. After receiving the voice m essage, the receiver owner has to flip the switch back toits original position to be in readiness to receive any subsequent paging call.

The switch for voice message connects the output from detector directly to the headphone. For reception of paging signal the switch connects the headphone to the UJT oscillator.

CHAPTER 6

SOME HARDWARE CONSIDERATIONS

6.1 Theory and practice always tend to differ to a certain extent. It is therefore intended to mention here a few points of practical interest. Also there is that inevitable "scope for improvement". Hence a little speculation on these lines appears warranted.

6.2 SIZE CONSIDERATIONS

The components used in the receiver and transmitter are of indigeneous origin. The receiver circuitry envisaged is not complex and uses a fairly low number of components. There are only 10 transistors, 7 digital IC chips and associated circuit elements. A photograph of the receiver is affixed on the facing page. Its overall dimensions are 15 cms x 7 cms x $3\frac{1}{2}$ cms, a size slightly on the larger side for a shirt pocket. The size was dictated by the individual components many of which were not miniature. They were used because of their 'off the shelf' availability. Also the pc card size was dictated by the available etching technique. With a careful layout and superior etching techniques, it is

possible to achieve a smaller p.c. card. Further, conventional soldering technique demands a minimum spacing of components because of accessibility considerations of soldering points by the soldering iron. With dip soldering techniques packing density could be increased resulting thereby in overall size reduction of the receiver.

6.3 CIRCUIT AND DEVICES

Quad 2 input NAND gates are available on one IC chip. To reduce the IC count, both the monostable and astable multivibrators were connected up using the same IC. However, it was observed that there was interaction and the individual timings could not be adjusted independent of each other. There was also a tendancy for wrong locking up of edges. This was so because of the spike that occurs in the output circuit of the TTL logic whenever a transistor is cut off thereby causing interaction through the common power supply line. Hence the two multivibrator circuits had to be connected up using two separate ICs after suitably decoupling the power supply to each for isolation.

There is one inherent drawback in using these logic gates in multivibrator configurations. Such circuits rely on the threshold of the device which may vary from one IC

to another. So associated with an IC replacement the timings have to be readjusted.

In order to minimise the loading effects on timing circuits (which causes change in timings) it is preferrable to use a buffer device like an inverter buffer between the source and load.

6.4 POWER SUPPLY

In paging applications the receiver size gets a paramount importance. Hence there is a need for using a small sized battery like the ones to be found in pocket size commercial receivers. In the present application the standing drain is about 8 mA and the peak current is 100 mA. An indigeneous 9V miniature power pack was used and it was found to be lacking because the output voltage dropped down to 7.5 volts. This poor regulation is attributable to high internal impedance. Either a similar dry cell with superior performance could be used or alternatively rechargeable NiCd batteries could be used. The advantages of the latter have already been mentioned.

By using MOS devices for logic, the existing current consumption could be substantially reduced. However MOS devices are not indigenously available as yet.

CHAPTER 7

CONCLUSION

7.1 In the foregoing chapters a methodology has been developed for designing a selective signalling system which can operate in a confined area of space or locality. The concepts underlying the methods of originating a selective signal, its reception and processing are reliable and realisable in pratice. The suggested prototype does not envisage use of any sophisticated techniques and hardware wise its execution is also not complex. In fact the digital techniques employed for generating and processing the code could be used in toto for application in selective signalling systems of other types, e.g. VHF carrier system.

7.2 With the growth of the state of art in hardware technology indigenously one can visualise an enormous system simplification. As an illustrative example, the system could use FSK and at the receiver end one could use a single phase lock loop IC chip and a single serial to parallel convertor IC chip, thereby dispensing with the detector, buffer, wave shaping unit and all the circuitry associated with the serial to parallel conversion of incoming code. The receiver size would then become

really miniature, which is a great advantage in paging applications.

7.3 Need there be, the same inductive loop system can be extended to cover fairly larger areas by laying adjoining loops which work on the receive-retransmit principle. However, extensive survey and field intensity measurements have to be made before embarking on a project of this nature.

7.4 There is one interesting extension possible to this inductive loop method of selective signalling in built up areas, namely the power line carrier system. The selective signal could be injected into the power system by suitable means. The transmission of intelligence can take place simultaneously with the electrical energy and without mutual interference. The receivers can operate on the principle of induction.

7.5 In Chapter 4, an expression has been developed for calculating the near field intensity of the loop antenna. With a knowledge of the receiver sensitivity one can obtain the minimum field strength that should exist at any particular point for satisfactory receiver operation. Knowing that the magnetic field intensity is directly related to the current flowing into the loop, one can

calculate the current requirements to give the required minimum field strength. This is the theoretical approach. However there might be losses due to shielding in RCC structures. Published reports which enable estimation of this kind of loss could not be traced. However, it is a customary engineering practice before establishing any communication link to carry out preliminary trials by measuring field strength at various points before deciding on power levels. This method is more preferred and reliable than theoretical calculations. In the present application it is suggested that such an approach be adopted.

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APPENDIX 1

For the purpose of programming the end result derived had to be arranged into a neater form and the partial derivative worked out. It is arranged as below.

$$P(x) = P_1 \ln [(\frac{P_2 + \sqrt{P_4 + x_1^2}}{P_3 + \sqrt{P_5 + x_1^2}}] * (\frac{P_6 + \sqrt{P_8 + x_2^2}}{P_7 + \sqrt{P_9 + x_2^2}})]$$

Let the first half of expression be equal to A and the second half equal to B.

$$\frac{\partial P(x)}{\partial x} = P_1 \times \frac{1}{AB} \{ B \times \frac{\partial A}{\partial x} + A \times \frac{\partial B}{\partial x} \}$$

$$\frac{\partial A}{\partial x} = \frac{\partial}{\partial x} \left(\frac{P_1 + \sqrt{P_3 + x_1^2}}{P_2 + \sqrt{P_4 + x_1^2}} \right)$$

$$= \frac{[(P_2 + \sqrt{P_4 + x_1^2} \times \frac{x_1}{\sqrt{P_3 + x_1^2}} - [(P_1 + \sqrt{P_3 + x_1^2}) \frac{x_1}{\sqrt{P_4 + x_1^2}}))}{(P_2 + \sqrt{P_4 + x_1^2})^2}$$

Listing of the program is given on next page.

```
$IBJOB
$IBFTC MAIN
      DIMENSION ARRAY(80,80)
      DATA ZERO/3H$$$/
      INP=5
      IOUT=6
1000  FORMAT(4F10.4)
      READ(INP,1000)AL,AA,AB,CURNT
      CONST=CURNT/(4.0*3.14159)
      BL=AL
      BA=AA
      AB=AB+5.0
      IK=2.0*AB+1.10
      AL=AL+5.0
      IL=2.0*AL+1.10
      AA=AA+5.0
      IA=AA*2.0+1.10
      H=1.0E+32
      WRITE(IOUT,1006)
1006  FORMAT(////////////////////1H1)
      DO 300 K=1,IK
      AK=K
      Y=AB-AK+1.0
      IF(Y+0.5)42,41,41
41    DO 200 I=1,IL
      AI=I
      Z=AL-AI+1.0
      IF(Z+0.5)43,44,44
44    ZAB=Z-BL
      ZCD=Z+BL
      ZA=ZAB*ZAB
      ZB=ZCD*ZCD
      DO 100 J=1,IA
      AJ=J
      X=AA-AJ+1.0
      IF(X+0.5)46,47,47
47    XAB=X-BA
      XCD=X+BA
      XA=XAB*XAB
      XB=XCD*XCD
      IF(Y)8,11,8
11    IF(XAB)1,1,4
1     IF(XCD)4,2,2
2     IF(ZAB)3,10,3
3     IF(ZCD)4,10,4
4     IF(ZAB)5,5,8
5     IF(ZCD)8,6,6
```

```
$IBJOB
$IBFTC MAIN
      DIMENSION ARRAY(80,80)
      DATA ZERO/3H$$$/
      INP=5
      IOUT=6
1000  FORMAT(4F10.4)
      READ(INP,1000)AL,AA,AB,CURNT
      CONST=CURNT/(4.0*3.14159)
      BL=AL
      BA=AA
      AB=AB+5.0
      IK=2.0*AB+1.10
      AL=AL+5.0
      IL=2.0*AL+1.10
      AA=AA+5.0
      IA=AA*2.0+1.10
      H=1.0E+32
      WRITE(IOUT,1006)
1006  FORMAT(/////////////////////1H1)
      DO 300 K=1,IK
      AK=K
      Y=AB-AK+1.0
      IF(Y+0.5)42,41,41
41    DO 200 I=1,IL
      AI=I
      Z=AL-AI+1.0
      IF(Z+0.5)43,44,44
44    ZAB=Z-BL
      ZCD=Z+BL
      ZA=ZAB*ZAB
      ZB=ZCD*ZCD
      DO 100 J=1,IA
      AJ=J
      X=AA-AJ+1.0
      IF(X+0.5)45,47,47
47    XAB=X-BA
      XCD=X+BA
      XA=XAB*XAB
      XB=XCD*XCD
      IF(Y)8,11,8
11    IF(XAB)1,1,4
1     IF(XCD)4,2,2
2     IF(ZAB)3,10,3
3     IF(ZCD)4,10,4
4     IF(ZAB)5,5,8
5     IF(ZCD)8,6,6
6     IF(XAB)7,10,7
```

```
 7     IF(XCD)8,10,8
 8     CALL PATDE (CONST,ZAB,ZCD,XA+ZA,XA+ZB,ZCD,ZAB,XB+ZB,XB+ZA,Y,
       CALL PATDE (-CONST,ZAB,ZCD,Y*Y+ZA,Y*Y+ZB,ZCD,ZAB,Y*Y+ZB,Y*Y·
      1,XAB,XCD,HY1)
       CALL PATDE (CONST,XAB,XCD,Y*Y+XA,Y*Y+XB,XCD,XAB,Y*Y+XB,Y*Y
      1ZAB,HY2)
       CALL PATDE (-CONST,XAB,XCD,XA+ZB,XB+ZB,XCD,XAB,XB+ZA,XA+ZA,Y,
      1)
       IF(HX1-ZERO)81,12,81
 81    IF(HY1-ZERO)82,12,82
 82    IF(HY2-ZERO)83,12,83
 83    IF(HZ2-ZERO)84,12,84
 84    ARRAY(I,J)=SQRT(HX1*HX1+(HY1+HY2)*(HY1+HY2)+HZ2*HZ2)
       IF(H-ARRAY(I,J))100,100,9
 12    WRITE(IOUT,1008)X,Y,Z,XAB,XCD,ZAB,ZCD
 1008  FORMAT(1X,*  ERROR  *,10F10.4)
       WRITE(IOUT,1009)X,Y,Z,XAB,XCD,ZAB,ZCD
 1009  FORMAT(10(1X,O12))
       GO TO 10
 9     H=ARRAY(I,J)
       HK=Y
       HI=Z
       HJ=X
       GO TO 100
 10    ARRAY(I,J)=0.0
 100   CONTINUE
 46    KLJ=J-1
       WRITE(IOUT,1001)Z,(ARRAY(I,J),J=1,KLJ)
 1001  FORMAT(1X,F5.1,5X,15F8.5/(11X,15F8.5))
       PUNCH 1007,Z,(ARRAY(I,J),J=1,KLJ)
 1007  FORMAT(1X,F5.1,7F10.5/(6X,7F10.5))
 200   CONTINUE
 43    DO 400 J=1,IA
       AJ=J
       ARRAY(1,J)=AA-AJ+1.0
       IF(ARRAY(1,J)+0.5)45,400,400
 400   CONTINUE
 45    KLJ=J-1
       WRITE(IOUT,1002)
       WRITE(IOUT,1010)Y,(ARRAY(1,J),J=1,KLJ)
       PUNCH 1007,Y,(ARRAY(1,J),J=1,KLJ)
 1010  FORMAT(1X,F5.1,5X,15F8.2/(11X,15F8.2))
 1002  FORMAT(///)
       WRITE(IOUT,1002)
 300   CONTINUE
 42    WRITE(IOUT,1002)
       WRITE(IOUT,1002)
       WRITE(IOUT,1003)H,HK,HI,HJ
```

```
1003   FORMAT(10X,* MIN VALUE *,F8.5,*  AT  Y,Z,X *,3F10.2)
       WRITE(IOUT,1000)
       STOP
       END
$IBFTC SUB1
       SUBROUTINE PATDE (P1,P2,P3,P4,P5,P6,P7,P8,P9,VAR1,VAR2,VAL)
       DATA ZERO/3H$$$/
       CALL PDIFF(P2,P3,P4,P5,VAR1,TEMP1)
       CALL PDIFF(P6,P7,P8,P9,VAR2,TEMP2)
       IF(TEMP1-ZERO)91,6,91
91     IF(TEMP2-ZERO)92,6,92
92     IF(ROOT(P3,P5,VAR1))3,6,3
3      IF(ROOT(P7,P9,VAR2))4,6,4
4      A=ROOT(P2,P4,VAR1)/ROOT(P3,P5,VAR1)
       B=ROOT(P6,P8,VAR2)/ROOT(P7,P9,VAR2)
       IF(A*B)5,6,5
5      VAL=P1*(TEMP2*A+TEMP1*B)/(A*B)
       RETURN
6      VAL=ZERO
       RETURN
       END


$IBFTC SYB2
       SUBROUTINE PDIFF(P1,P2,P3,P4,VAR,VAL)
       DATA ZERO/3H$$$/
       TEMP1=SQRT(P4+VAR*VAR)
       TEMP2=SQRT(P3+VAR*VAR)
       TEMP3=P2+TEMP1
       TEMP4=P1+TEMP2
       IF(TEMP1)1,4,1
1      IF(TEMP2)2,4,2
2      IF(TEMP3)3,4,3
3      TEMP5=TEMP3*VAR/TEMP2
       TEMP6=TEMP4*VAR/TEMP1
       VAL=(TEMP5-TEMP6)/(TEMP3*TEMP3)
       RETURN
4      VAL=ZERO
       RETURN
       END


$IBFTC SUB3
       FUNCTION ROOT(P1,P2,VAR)
       ROOT=P1+SQRT(P2+VAR*VAR)
       RETURN
       END
```

DATA CARD SPECIFIED AS BELOW
HALF LOOP DIMENSIONS ARE 5 MTS BY 8 MTS
THIRD QTY REPRESENTS NO. OF ITERATIONS,IF 0.0 6 ITERATIONS IN Y DIR
CURRENT IN THE LOOP IS 0.168 AMPS
****
INPUT DATA CARD BELOW

5.0 8.0 0.0 0.168

****

Z MTS	X IN MTS					
	13.00000	12.00000	11.00000	10.00000	9.00000	8.00000
	6.00000	5.00000	4.00000	3.00000	2.00000	1.00000
10.0	0.00062	0.00072	0.00084	0.00096	0.00109	0.00123
	0.00147	0.00157	0.00166	0.00172	0.00177	0.00179
9.0	0.00072	0.00085	0.00099	0.00116	0.00134	0.00152
	0.00185	0.00198	0.00209	0.00217	0.00222	0.00226
8.0	0.00082	0.00099	0.00118	0.00140	0.00164	0.00189
	0.00233	0.00250	0.00263	0.00273	0.00279	0.00283
7.0	0.00094	0.00114	0.00139	0.00168	0.00200	0.00233
	0.00291	0.00312	0.00328	0.00339	0.00346	0.00350
6.0	0.00106	0.00131	0.00162	0.00199	0.00241	0.00283
	0.00356	0.00381	0.00399	0.00411	0.00419	0.00423
5.0	0.00118	0.00147	0.00185	0.00230	0.00282	0.00335
	0.00422	0.00450	0.00469	0.00481	0.00488	0.00491
4.0	0.00128	0.00163	0.00206	0.00260	0.00320	0.00382
	0.00479	0.00509	0.00527	0.00538	0.00545	0.00548
3.0	0.00138	0.00176	0.00224	0.00284	0.00351	0.00419
	0.00523	0.00553	0.00570	0.00580	0.00585	0.00587
2.0	0.00145	0.00185	0.00238	0.00302	0.00374	0.00445
	0.00552	0.00581	0.00597	0.00605	0.00609	0.00610
1.0	0.00149	0.00192	0.00246	0.00312	0.00386	0.00460
	0.00567	0.00596	0.00611	0.00618	0.00621	0.00622
-0.0	0.00151	0.00194	0.00249	0.00316	0.00391	0.00465
	0.00572	0.00600	0.00615	0.00622	0.00625	0.00626

ABOVE VALUES ARE AT A HEIGHT OF 5 MTS ********************************

10.0	0.00067	0.00079	0.00092	0.00108	0.00125	0.00143
	0.00176	0.00190	0.00200	0.00209	0.00214	0.00218
9.0	0.00078	0.00094	0.00113	0.00135	0.00161	0.00187
	0.00236	0.00255	0.00269	0.00280	0.00287	0.00292
8.0	0.00091	0.00112	0.00139	0.00171	0.00210	0.00251
	0.00323	0.00350	0.00369	0.00382	0.00391	0.00396
7.0	0.00106	0.00133	0.00170	0.00218	0.00277	0.00341
	0.00450	0.00485	0.00509	0.00524	0.00534	0.00540
6.0	0.00121	0.00157	0.00207	0.00276	0.00364	0.00464
	0.00617	0.00659	0.00684	0.00700	0.00709	0.00713
5.0	0.00137	0.00182	0.00246	0.00339	0.00463	0.00602
	0.00794	0.00834	0.00855	0.00865	0.00870	0.00872
4.0	0.00152	0.00205	0.00283	0.00397	0.00551	0.00720
	0.00923	0.00952	0.00961	0.00962	0.00961	0.00960
3.0	0.00165	0.00225	0.00313	0.00443	0.00616	0.00797
	0.00985	0.00998	0.00995	0.00987	0.00979	0.00975
2.0	0.00174	0.00239	0.00335	0.00474	0.00655	0.00838
	0.01005	0.01006	0.00993	0.00978	0.00966	0.00959
1.0	0.00180	0.00248	0.00348	0.00491	0.00675	0.00857
	0.01010	0.01003	0.00983	0.00964	0.00950	0.00941
-0.0	0.00182	0.00251	0.00352	0.00497	0.00681	0.00863
	0.01010	0.01001	0.00979	0.00958	0.00944	0.00935

ABOVE VALUES ARE AT A HEIGHT OF 3 MTS ************************************

10.0	0.00068	0.00081	0.00095	0.00112	0.00131	0.00151
	0.00188	0.00203	0.00215	0.00224	0.00231	0.00234
9.0	0.00080	0.00097	0.00118	0.00143	0.00172	0.00203
	0.00260	0.00282	0.00299	0.00312	0.00320	0.00325
8.0	0.00094	0.00117	0.00147	0.00185	0.00232	0.00284
	0.00376	0.00409	0.00433	0.00449	0.00460	0.00466
7.0	0.00110	0.00141	0.00184	0.00244	0.00324	0.00417
	0.00573	0.00620	0.00653	0.00671	0.00683	0.00690
6.0	0.00127	0.00168	0.00229	0.00322	0.00461	0.00635
	0.00891	0.00948	0.00980	0.01000	0.01011	0.01017
5.0	0.00145	0.00197	0.00279	0.00413	0.00634	0.00926
	0.01258	0.01290	0.01315	0.01323	0.01326	0.01327
4.0	0.00161	0.00224	0.00326	0.00499	0.00789	0.01155
	0.01437	0.01431	0.01416	0.01402	0.01393	0.01387
3.0	0.00176	0.00247	0.00364	0.00564	0.00888	0.01263
	0.01437	0.01387	0.01344	0.01313	0.01293	0.01283
2.0	0.00189	0.00264	0.00391	0.00605	0.00942	0.01306
	0.01399	0.01320	0.01259	0.01218	0.01192	0.01178
1.0	0.00193	0.00274	0.00407	0.00627	0.00968	0.01323
	0.01371	0.01278	0.01209	0.01161	0.01132	0.01116
-0.0	0.00195	0.00278	0.00412	0.00634	0.00975	0.01327
	0.01361	0.01264	0.01191	0.01143	0.01113	0.01096

ABOVE VALUES ARE AT A HEIGHT OF 2 MTS ************************************